CLIMATE CHANGE AND THE FLORIDA KEYS

By Hans Hoegh-Guldberg

MAIN REPORT

APPENDICES AND BACKGROUND PAPERS IN SEPARATE FILES

JULY 21, 2010 (November 17, 2010 update)

SOCIOECONOMIC RESEARCH AND MONITORING PROGRAM

FLORIDA KEYS NATIONAL MARINE SANCTUARY (FKNMS)

NATIONAL ATMOSPHERIC AND OCEANIC ADMINISTRATION (NOAA)

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ABSTRACT

This research is part of the Socioeconomic Research and Monitoring Program for the Florida Keys National Marine Sanctuary (FKNMS), which was initiated in 1998.

The main report concerns the Florida Keys. It includes two appendices that identify key issues related to the future of the Keys over the 21st century. Four background papers deal with the global environment (Hoegh-Guldberg 2010a,b,c,d). They are described first to put the Florida Keys into context.

The global environment: The threat of global climate change has grown over very few years from urgent to “red alert” according to the vast majority of climate scientists. Better climate models showing positive feedback have dramatized the evidence, but more importantly what were previously considered worst cases have moved closer to the center of the probability distribution. Global factors are therefore even more crucial than when this project was first planned in 2005.

The research is derived from the four global scenarios originally developed for the Third Assessment Report of the Intergovernmental Panel on Climate Change in 2001 – alternative scenarios showing the consequences of taking no corrective action through climate policy. Despite their age, the scenario stories still form a reasonably updatable framework, but the numerical implications are no longer acceptable. The current scientific consensus is that atmospheric CO_2 levels of 450 parts per million or more will be quite unsafe. To keep average global warming to a maximum $2^{O}C$ above pre-industrial levels means reducing the CO_2 from the 2009 level of 388 ppm to 350 ppm or less (Hoegh-Guldberg 2010a).

A second background paper (Hoegh-Guldberg 2010b) challenges the assumption in the IPCC scenarios that world economic growth would be unaffected by global warming – even when growing towards 4, 5, and $6^{O}C$ above pre-industrial levels. It uses a simple model to show that in some “worst” cases, and even some “most likely” cases, the world GDP could begin falling in the second half of the century – which would be unpredictably disruptive. Only the global environmental scenario B1 would produce uninterrupted economic growth through the century.

Another concern is that economic theory itself has failed to guide major government policy directions to deal with climate change and the global financial crisis. Economics needs to change some of its basic assumptions and mesh more with other disciplines (Hoegh-Guldberg 2010c).

The final background paper (Hoegh-Guldberg 2010d) discusses technologies that may help save the planet from the impact of climate change. They fall into three groups: technologies to develop renewable and other energy sources, energy efficiency, and retaining and developing land-based and coastal carbon sinks. It is also essential to keep diffusing technologies from rich to developing countries and even more to encourage the invention of genuinely new technologies in more countries, not just the United States and other first-world nations. Worldwide technological development will be vital in the fight against climate

change in the 21st century, and it is encouraging that more countries have started to develop innovative technologies.

The Florida Keys are the most vulnerable part of what is the mainland US State most vulnerable to climate change. The Keys are equivalent, in practice, to Monroe County. The following points cover first biophysical factors, and then some main socioeconomic consequences:

1. The main threat is from sea-level rise, which even in the best-case scenario could inundate 38% of the current land area (in the worst case practically the whole area). More violent and frequent hurricanes will exacerbate this threat.
2. Elevated sea temperature is the primary influence on the coral reef, aggravated by acidification.
3. These factors reinforce traditional stressors including land-based pollution, overfishing, destructive fishing practices, invading species, and disease.
4. The coral cover of the reefs around the Florida Keys declined by half between 1996 and 2008. Commercial fishery landings in Monroe County showed similar declines, including reef fish (snappers, groupers), spiny lobsters, and pink shrimp.
5. Water supply is basically from outside the Keys, through aquifers. It is already being affected by saltwater intrusion, which would be aggravated by further sea-level rise.
6. Carrying capacity is a key issue for Monroe County. Partly as a result of its residential permit control, the population has been declining since 1996.
7. This trend is being intensified by structural economic and demographic change, with a large increase in the number of non-residents owning or leasing condominiums and share-type accommodation. It also shows up in the employment structure in Monroe County, with a 60% increase in the real estate sector while the main categories associated with the hospitality industry and retail trade have stagnated or declined.
8. The mainstay of the Keys economy, tourism, also remained largely static between 1995-96 and 2007-08, according to the major NOAA visitor surveys. Moreover, the tourists now tend to seek land-based rather than sea-based activities, with an increasing concentration on the historic center of Key West.
9. Finally, living close to a major population center of 5.5 million people has a multitude of consequences, most of them adding to the risks faced by the Florida Keys despite strong local and regional government action to manage the situation.

These are formidable challenges for the Florida Keys. Both the County and the Sanctuary are managing the situation as effectively as they can. The key is increasing resilience, applied primarily to the coral reef but relevant beyond. Although still difficult to manage, some control is possible over reef health, sustainability, and fisheries, local pollution, the economy and its main driver, tourism, and how to use education and outreach effectively.

These are all part of the armory of the integrated coastal and marine management system within which the FKNMS operates – multiple jurisdictions working with other federal, state and local agencies. The local community also plays a major role, with the Sanctuary Advisory

Council meeting with FKNMS executives on a bimonthly basis since 1992. Local community organizations are also exerting increasing influence and support.

Policy recommendations: The report concludes with a set of recommendations which basically warns in the strongest possible terms against continuing a "business-as-usual" policy but ensuring that a global and national environmentally friendly regime be introduced with all possible speed. In terms of our scenarios, the choice must be "B1". While the action to achieve this has to be global and national, the position of the Keys as America's most threatened area suggests that the state of Florida, the FKNMS, and Monroe County are well positioned to take a strong advocacy role in the global and national policy formulation.

ACKNOWLEDGMENTS

The origin of this project can be traced to two events, occurring more than a decade ago. In 1997, I became interested in scenario planning while pursuing another interest, resulting in the writing of four scenarios for Indonesia's future following the collapse of the Soeharto regime. Simultaneously, a life-long friend and colleague in the United Kingdom, Professor David Stout, became involved in scenario planning for different reasons, and a lively correspondence ensued. David keeps feeding a broad range of ideas from American and British newspapers and journals, which has inspired this project.

Then my son, Professor Ove Hoegh-Guldberg of the University of Queensland, wrote a seminal paper on coral bleaching in 1999 (references at end of report), which caused Greenpeace to ask him to add the socioeconomic impacts on local communities to a review of coral bleaching in the Pacific. I was called upon at short notice to contribute this research for *Pacific in Peril* (2000), and co-wrote the scenario content with David Stout. The Greenpeace project led WWF Australia to ask Ove and me to write a joint study of the Great Barrier Reef (published in 2004), which again led to the current project. Ove naturally remains in close contact and has provided valuable advice on many sections of this report.

Living outside a small highland town west of Sydney, Australia, modern communications technology is essential. It has provided constant contact with people in the Florida Keys and worldwide, without which this project simply couldn't have been undertaken. Of course, it would have been equally impossible to undertake the project without visiting the Keys, which happened on four occasions during the extended period it took to complete the work.

My ongoing contact was Bob Leeworthy, Chief Economist in the NOAA/NOS Office of Marine Sanctuaries. Bob has been unfailingly helpful and it is nice to find a fellow economist who agrees that climate change and global crisis are forcing a major re-appraisal of economic thought.

Several other persons made truly appreciated contributions to earlier drafts. David Stout painstakingly read through one version for accuracy and clarity. TNC's Chris Bergh read a early draft of the main report and made many helpful comments. He also made an important contribution to my concept of the Keys as a higher-order ecosystem (Chapter 3.3), and his paper on sea-level rise in the Keys is central. Jim Bohnsack, John Hunt and Bill Sharp provided important advice on the biophysical Chapter 5. A distinguished Danish biotechnologist, Professor John Villadsen, read the first draft of the background technology paper (Hoegh-Guldberg 2010d) in detail and made numerous constructive suggestions across a range of technologies. EcoAdapt's Lara Hansen and Alex Score (formerly WWF) read and commented comprehensively on a set of prototype policy recommendations, reported fully in Chapter 8. Needless to say, I am responsible for the actual versions, warts and all, but hardly any editing was needed and certainly no blemishes attach to Lara's and Alex's list of recommendations.

Billy Causey, Southeast Regional Director for NOAA's National Marine Sanctuary Program, and Chris Bergh, The Nature Conservancy's Florida Keys Director, have been unstinting with their support and friendship. Friendliness and helpfulness are words that comes easily to mind with people in the Keys – Dolly Garlo, Judy and John Halas, Susan Ford Hammaker, Tina

and Dennis Henize, Alison Higgins, Martin Moe, Anne Morkill and George Neugent, to name but a few. More are mentioned below.

There were two reasons for visiting the Keys, apart from the obvious need to gain personal experience of the area. One was to conduct scenario-planning workshops in 2008 (and follow-up meetings a year later), with vital help from three Chamber of Commerce directors, Jackie Harder, Judy Hull, and Carole Stevens, and Craig Wanous of the Eco-Discovery Center in Key West. Jennifer Belz from Veritext provided support beyond the call of duty as well as producing painstakingly accurate verbatim records of the workshops. Debra Illes kindly made the Diving History Museum available for the follow-up meeting in Islamorada in 2009.

The second reason for visiting was to gather information on biophysical and other data. Billy Causey and his colleagues Brian Keller, Sean Morton and Scott Donahue set the stage (sadly, Brian passed away in March 2010; he and Fiona Wilmot were my first Florida Keys contacts back in 2005). Meetings were held with John Hunt and his colleagues from the Fisheries and Wildlife Research Institute (Alejandro Acosta, Rod Bertelsen, Mike Feeley, Bob Glazer, Tom Mathews, and, in absentia, Rob Ruzicka and Mike Colella who provided full data on coral cover from the CREMP program), Steve Miller and Mark Chiappone of the University of North Carolina-Wilmington, Key Largo, David Vaughan of MOTE Laboratories, George Garrett of the City of Marathon, and Patricia Bradley who provided useful background on EPA. Holly Merrill advised on State legislation matters, and Julie Cheon helped confirm my water supply notes. Jessica Bennett, market research director of the Monroe County Tourist Development Council, was helpful with statistical advice.

I also benefited from contact with NOAA's Joe Schittone and Dwight Gledhill and the Director of TNC's Insular Caribbean Program Phil Kramer, and took the opportunity to call on Gregor Hodgson at the Reef Check Foundation, Pacific Palisades, CA, while staying in Los Angeles before returning to Australia in August 2009.

The 2008 workshops themselves were attended by 60 community and business leaders from the Florida Keys, who contributed to what became a highly valuable record. They made up a true cross-section of concerned younger and older citizens, who in addition to persons already mentioned included Douglas Bedgood, Michelle Beighley, Bette Brown, Jared Brown, Bob Calhoun, Heather Carruthers, Cheryl Cioffari, Clay Crockett, Hallett Douville, Shirley Freeman, Peter Frezza, Richard Grathwohl, Doug Gregory, Audra Hill, Rick Hill, Bob Holston, Paul Johnson, Wayne Markham, Pam Martin, MaryAnn Nichols, Derek Norman, Jason O'Brien, Glenn Patton, DeeVon Quirolo, Cece Roycraft, Lila and Douglas Rudolph, Audrey and John Sahagian, Tim Saunders, Harvey Server, Carol Shipley, Rob Silk, Margie Smith, Dixie Spehar, Terry Strickland, Cal Sutphin, Ty Symroski, David Tuttle, Vicky Walker, Jodi Weinhofer, Tom Wilmers, and Shirley Wilson.

To sum up, this project has benefited from the help of a cast of, if not thousands, at least many dozens of very helpful people. Apologies to anyone I have inadvertently missed out.

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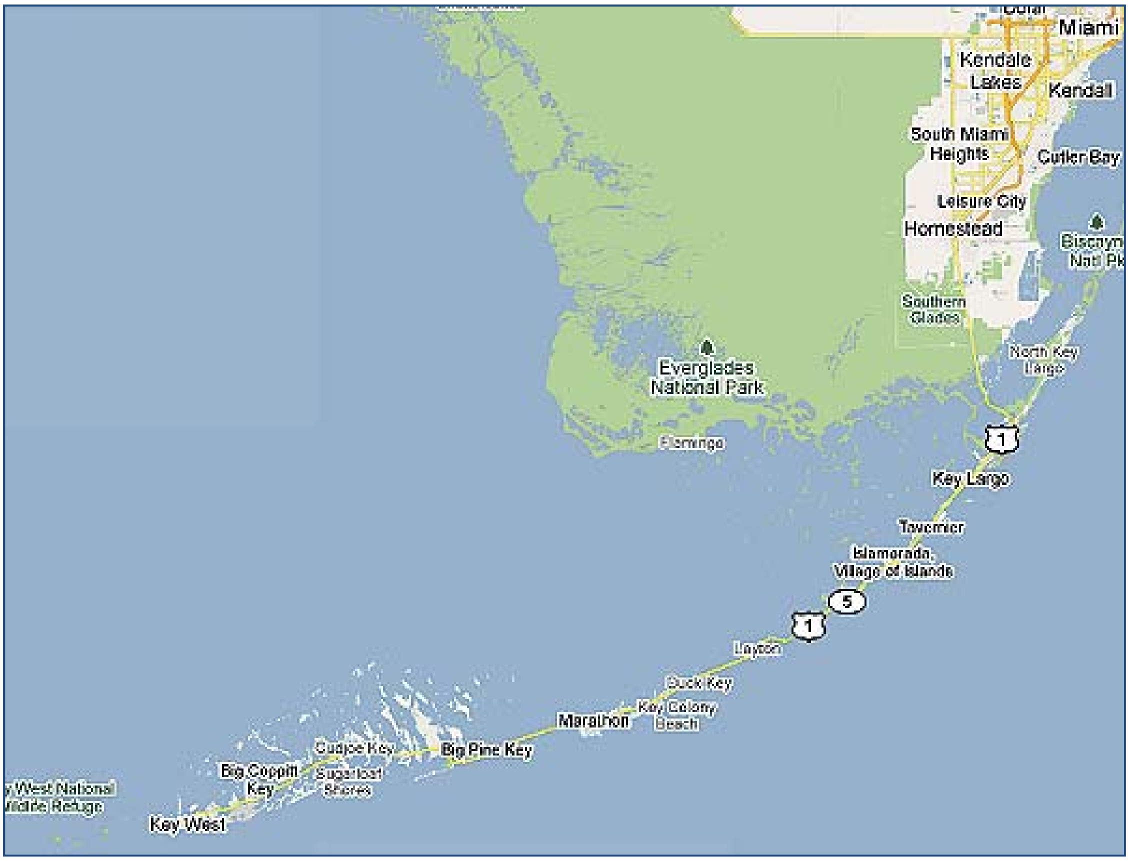
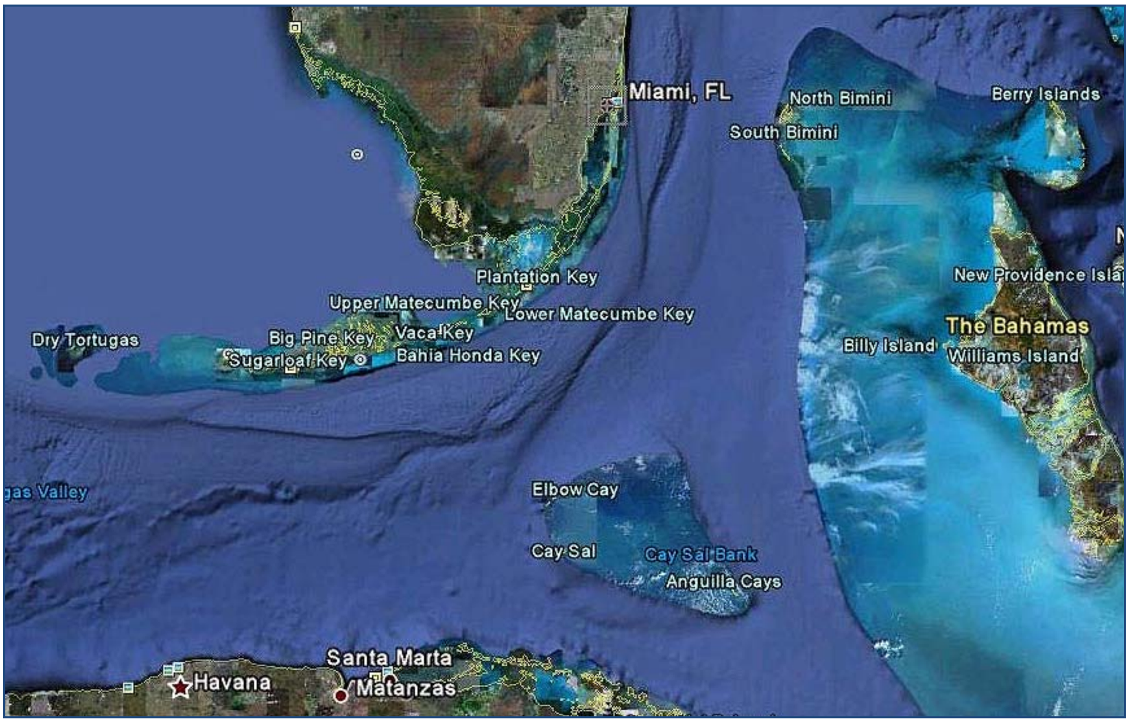
THE LOCATION





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MAIN REPORT

1 SYNOPSIS

1.1 TACKLING GLOBAL CLIMATE CHANGE HAS BECOME CRITICALLY URGENT

The period during which this project has been researched, since the scoping report for NOAA five years ago (Hoegh-Guldberg 2005), straddles extraordinary change. The majority of climate scientists agree that combating climate change has become much more urgent over the past five years, but more recently the world has been plunged into the worst recession since the 1930s. This has weakened the public and political will to tackle a "long-term" problem, not least in the United States which has lagged behind in the economic recovery process. New battle lines have been drawn up between those politicians and other citizens that advocate urgent action, and those who choose to see climate change as grossly exaggerated or not urgent. The global and local scenarios in Chapter 7 reflect this conflict.

The brief for the project is to study the implications of climate change in the Florida Keys with special focus on the surrounding marine area with its coral reefs. It was modeled on a study of the Great Barrier Reef in Australia (Hoegh-Guldberg and Hoegh-Guldberg 2004), which explored the available scientific, socioeconomic and environmental evidence and projected conditions to the end of the 21st century based on the four scenarios produced for the Third Assessment Report of the Intergovernmental Panel on Climate Change in 2001. The scenario storylines and associated numerical projections, based on research undertaken in the late 1990s, are described in the IPCC's *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000).

Funds were initially allocated in 2005 to allow the Florida Keys project to be planned in cooperation with NOAA (Hoegh-Guldberg 2005). The project subsequently received approval of the requested funding for the fiscal years 2007-08 and 2008-09. It became increasingly clear, however, that the IPCC's assumptions were falling behind: climate models had begun to incorporate large positive feedback effects and new scientific evidence showed climate change exceeding what was anticipated in the 1990s. The evidence built up dramatically that the world could no longer tolerate a large increase in greenhouse gases – on the contrary, the scientific evidence now indicates that the amount of carbon dioxide in the atmosphere should be reduced, and the average global temperature increase limited to 2^{O}C.

These changes forced a shift in the relative weight of global and local research for the project. It became essential to explore how the changes in the climate change outlook worked out worldwide, in contrast to the Great Barrier Reef study which basically accepted the then fairly recent global scenarios from the *Special Report on Emissions Scenarios* to concentrate more fully on the local scene. We can no longer do this in 2010, though it was assumed in the scoping report for NOAA (Hoegh-Guldberg 2005) that we could.

The updated global perspective is explained in the next section. It is hoped that one advantage of spending so much extra effort on this perspective will be its application to a wider range of problems, as well as the Florida Keys.

1.2 GLOBAL CHANGE

Chapter 2 summarizes four background papers for the main report which proved seminal for the development of local scenarios for the Florida Keys. They deal with elements that were less recognized or appeared less important or had not yet shown up as serious when the global scenarios were developed for IPPC's Third Assessment Report in 2001. Recent events show that these global elements have become critically important, and the background papers are essential reading for full understanding of what may happen in the Florida Keys.

The relative importance of the various manifestations of climate change is also changing. Global warming remains the determining factor but other dimensions have gained more prominence than was the case a decade ago. Sea-level rise is now seen as a greater threat in a shorter span of time; weather patterns are expected to include more frequent and probably also more violent storms, as well as more severe droughts and floods; ocean acidification was regarded as a minor factor but is now considered a major threat not just for coral reefs but for all calcareous marine organisms in the oceans (Hoegh-Guldberg 2010a).

Other considerations added further to the task of coming to grips with the global situation before tackling the local prospects in the Florida Keys. Both scientists and economists have written about exceedingly uncomfortable living conditions and deteriorating economic circumstances as global temperatures climb, but no one has tried to measure it. Hoegh-Guldberg (2010b) presents a simple model to introduce such projections.

Economic theory has a strong influence on the philosophy that drives government policy, not least in the 30 years leading up to the financial crisis in 2008, which was surprisingly unexpected considered the years of unusual behavior in the finance and property markets, especially in the United States. Because of this, there is a need to build economic policy assumptions into the scenarios to a greater extent than have been the case to date.

Hoegh-Guldberg (2010c) contains a review of what apparently went wrong with the economics, and shows how "the greatest market failure ever", climate change, was never built properly into the dominant macroeconomic model. In the process of reviewing its assumptions, some theoretical economic thinking now appears to be connecting more with social and physical sciences such as psychology and evolutionary biology, and with the interdisciplinary complexity theory developed mainly at the Santa Fe Institute in New Mexico.

This background paper (Hoegh-Guldberg 2010c) concludes with a review of events since the onset of the financial crisis which have obviously influenced public and political attitudes, with an upsurge in what has been termed "climate change denialism". These events are influencing economic theory and policy as well as having a negative effect on the political will to tackle climate change, which may be expected to linger on in those scenarios that most closely resemble "business-as-usual".

The final critical area is the pace of technological change, towards renewable energy, better energy efficiency, improving carbon sinks through forestry and reducing deforestation, developing better agricultural methods, and preserving seagrass beds, mangroves, and other coastal vegetation which provide essential conduits for actively transferring carbon dioxide from the atmosphere to the ocean. The final background paper (Hoegh-Guldberg 2010d) was inspired by the theory of technology developed by W. Brian Arthur of the Santa Fe Institute (Arthur 2009) – a theory that also helps explain the rate at which technologies get diffused worldwide, and in the process start providing a basis for true innovation in a widening range of countries.

1.3 NATIONAL AND REGIONAL PERSPECTIVES

While Florida and the Keys also reflect the larger US community, some vital opportunities and vulnerabilities obviously differ. This is the subject of Chapter 3. The United States provides the natural link between the broad global situation and prospects for the Florida Keys. Chapter 3 also looks for similarities in climate change vulnerability between Florida and other parts of the United States.

Both tasks were greatly assisted by a comprehensive report from the US Global Change Research Program (Karl et al. 2009), which describes the link between global climate change and the impact in the United States, and provides a regional analysis of climate change vulnerability.

On the former subject, it concludes that climate change in the United States is real, primarily human-induced, already happening, above the global average, and projected to increase with widespread effects on water, transportation, agriculture, ecosystems, and health. Thresholds will be reached, leading to large changes in climate and ecosystems.

Concerning regional similarities and differences, it notes that coastal areas including Florida and the rest of the US Southeast are increasingly vulnerable to sea-level rise and storm surges, with adverse effects very likely to be concentrated on energy and transportation infrastructure and other property in these areas. As well as sharing the adverse effect of increasing temperatures with practically every other US region, the Southeast is relatively vulnerable to climate change effects on water supply and ecosystems.

Generally, climate change will combine with pollution, population growth, overuse of resources, urbanization, and other social, economic, and environmental stresses to create larger impacts than from any of these factors alone.

1.4 FLORIDA KEYS OVERVIEW

Chapter 4 starts with a description of the physical, demographic and economic setting of the Florida Keys, highlighting the salient points relevant to climate change and the future of the area. The populated part of Monroe County stretches for 172 km along US Highway 1 from Key Largo in the Upper Keys, via Marathon in the Middle Keys, and via Big Pine Key and other islands in the Lower Keys, to the historic town of Key West.

The population of Monroe County is declining; growth is regulated through residential permits (Rate of Growth Ordinance, or ROGO). The economy of the Florida Keys is driven to an extraordinary extent by tourism and to a lesser extent by commercial fishing.

Apart from coral reefs, the Keys have a great variety of environmental resources, unique habitats for rare and endangered plant and animal species. The State of Florida in 1980 legislated to make the Keys portion of Monroe County an Area of Critical State Concern. Special management areas, in addition to the Florida Keys National Marine Sanctuary (FKNMS) and other national parks, include the John Pennekamp Coral Reef State Park off Key Largo, and numerous other parks of natural or historical significance, the latter concentrated on Key West featuring a center that is basically one large historic site. Monroe County's Board of Commissioners take an environmentally sensitive approach (as evidenced by ROGO). In 2008, they instituted a "Green Initiative Task Force" to recommend practices and techniques to protect the environment and mitigate against climate change.

The bulk of Chapter 4 (Section 2) deals with eight identified key issues of importance for the future of the area, based on five scenario-planning workshops in June 2008 organized as part of this project along the Keys from Key Largo to Key West. The issues are summarized in Appendix 1 based on an edited and shortened version of the actual transcripts (Appendix 2).

The issues fall into two groups. The first group consists of issues over which it is difficult or impossible to exercise any local control. Climate change was unanimously seen as the prime threat facing the Keys; the other issues were water supply, carrying capacity, and a group of external influences including pollution from the rest of Florida and from the Midwest through the Gulf of Mexico, and potential impacts following an opening up of Cuba.

The second group of issues are considered manageable (within the confines set by the first group): reef health, sustainability and fisheries; pollution; the economy, tourism and diversification potential; and the need for continued education and outreach.

Section 3 deals with the management of the area, focusing on the FKNMS. The integrated coastal management style of the Sanctuary facilitates collaboration with local, state and federal agencies with different powers to foster compatible management strategies and practices. The Sanctuary Advisory Council is an important local source of advice, founded in 1992 early in the life of the FKNMS and meeting ever since on a bimonthly basis. The members of SAC represent nominated scientific, environmental and commercial interests which have proved their consultative influence for upwards of twenty years.

The unifying theme for the management of these resources is *resilience*, increasingly important in conditions of accelerating climate change with its effects on sea temperatures, sea level, and ocean chemistry (acidification). It is a weakness, however, that only 6% of the FKNMS area is closed to all extractive users, and mainly in the Dry Tortugas rather than along the Keys. The issues in the Dry Tortugas are not being ignored by stating that the level of protection in the Keys will be increasingly inadequate as the climate continues to change.

Institutionally and through the expertise of its management and staff, FKNMS is judged to be excellently equipped to deal with climate change, with two provisos: funding must be adequate, and more so as climate change starts to bite. Outside the realm of local control, climate change must remain controllable.

The last section of Chapter 4 describes the important role of volunteer groups and non-government organizations in the area. Some act locally, such as GLEE (Green Living and Energy Education), SFFFK (Sanctuary Friends Foundation of the Florida Keys), and special-purpose societies protecting local endangered species like the key deer on Big Pine and No Name Keys. Others started locally but have developed a broader geographical scope, such as

Reef Relief. The Nature Conservancy is the leading major NGO active in the area, and the organization most closely identified with actions to build coral reef resilience.

1.5 BIOPHYSICAL RESEARCH

Coral cover in the Florida Keys Sanctuary declined from 12.3% in 1996 to 6.4% in 2008 according to the Coral Reef Evaluation and Monitoring Project (CREMP), which is part of the activities of the Fish and Wildlife Research Institute (FWRI), a Florida State agency. The deterioration is only the end, as of now, of a rapid development – the coral cover was probably in the order of 50% or more in the Caribbean as recent as the late 1970s, and the cover along the Keys was also much higher in decades gone by. Voss (1988) gives a classical account of how badly Florida's coral reefs had already degenerated by the late eighties.

A different approach to CREMP's is taken by Steven Miller and colleagues in a program that have brought many new insights since its start in 1999. The approach focuses on specific issues based on randomly stratified benthic sampling rather than mapping the decline in coral cover through repeated site surveys.

The FWRI also collects detailed statistics on landings of commercial fisheries, available annually since 1986 for a comprehensive range of individual fish and crustacean species, for each county of Florida.

Yearly landings in Monroe County totaled over 20 million pounds in the late 1980s but only half that weight in 2007 to 2009. Catches have fallen for all main groups documented in Section 5.3 for Monroe County but two main species of interest here have shown the least decline: reef fish (snappers, groupers and similar species), and spiny lobsters for which almost 90% of the total catch for Florida is landed in Monroe County. A third main species, pink shrimp, has showed more than average decline relative to the State.

The chapter on biophysical research concludes with a series of notes on relevant research in the Florida Keys carried out by scientists, to be seen as examples rather than an inclusive analysis. FWRI scientists have been studying the role of seagrass beds as nursery areas for commercially important reef fishes and the similar role of hardbottom areas for spiny lobsters under threat of siltation from coastal outflows. Research into queen conch living in different locations (near-shore versus offshore) suggests that there may be a connection between climate change and reproductive behavior at different site types.

Florida Bay between the mainland and the Upper Keys is of particular importance because its proximity to the Everglades makes it a channel of pollution into the Keys ecosystem. The FWRI is instrumental in carrying out strategic planning of how to improve the status of Florida Bay.

The final research project noted in Section 5.3 is by Jerald Ault, James Bohnsack, Jiangang Luo and Steven Miller, concerning overfishing of reef fish. The situation is complex because slow-growing, long-living groupers and hogfish suffer more from exploitation than other members of the "snapper-grouper complex".

1.6 ECONOMIC AND RELATED INDICATORS

The total US population has grown by a modest 1.1% per annum over the past 40 years, while Florida outpaced the nation considerably up to 2000, increasing its share of the total US population from 3.3% to 5.6%. The rate of change has slowed in recent years but Florida's population still reached 6.1% of the national population by 2008, growing to 18.1 million. A massive 5.5 million live in the South Florida Metropolitan Area (Miami-Dade, Broward, and Palm Beach Counties) immediately north of the Florida Keys.

The population in Monroe County (virtually all in the Keys) increased steadily between 1969 and 1993, from 52,500 to 82,200 persons (annual growth 1.9%). Since 1993, the Keys population has shrunk every year, to reach 73,300 in 2008 (an average annual decline of 0.8%).

Florida's economic growth (3.5% pa between 1997 and 2008) outpaced the 2.7% for the US despite setbacks in 2007 and 2008. Since 1997, personal income and Gross State Product trends have been parallel, which suggests that recent personal income data at county level are representative of total economic growth. Personal income at constant prices increased by 3.2% pa between 1997 and 2008 in Monroe County despite the population decline, suggesting structural change in the Florida Keys income distribution, boosted by wealthy immigrants.

Another noticeable feature is the employment growth between 1994 and 2008 in Monroe County despite the fall in population. In 2008, 57,900 persons worked there, while the total population had declined to 73,300. This very high ratio of workforce to population can only be explained by people working in the hospitality and retail trade industries who don't live in the Keys.

These two industries are the main employers in Monroe County, but both have been employing falling numbers between 2001 and 2008. The real estate industry, meanwhile, has increased its employment considerably, providing further evidence that structural change is happening, causing high turnover of property.

One indicator of tourism activity since 1995 is bed tax statistics adjusted for inflation and a changed tax rate from June 2009. Revenue from this Monroe County tax generally increased up to 2003 or 2004 but has fluctuated around a static trend since then. Similar flat trends apply to other tourism-related indicators such as taxable tourism and recreation-related sales, which amount to about 45% of total taxable sales, rising to 48% in 2008 and 2009.

These statistics, however, tell only part of the story. The most authoritative indicators are NOAA's visitor and resident surveys of 1995-96 and 2007-08, which are the subject of Section 6.4. They show that tourism accounted for 60% of total sales in both years, with the most significant structural change being a strong increase in the number of visitors using condominiums and time-share facilities rather than hotels, motels, resorts and camping facilities.

Passenger arrivals at Key West International Airport fluctuated after 1995, but after a peak in 2005 declined to levels not seen since 1995. Cruise ships delivered over a million passengers in Key West in 2002 and again in 2003, after strong growth. The number of cruise ship passengers has since declined to about 860,000 in 2009.

The 2007-08 version of NOAA's visitor and resident surveys finishes the section on socioeconomic monitoring of the Florida Keys, showing a decline in the average stay of tourists, and a strong trend toward land-based and away from sea-based activities. Spending by visitors for recreation purposes increased by more than would have been expected from the survey estimates of average person-trips (visits) and person-days in the Keys. As stated above, this was due to a strong increase in the number of people from outside Monroe County owning or leasing condominiums or time-share facilities in the Keys.

Importance and satisfaction ratings by tourists are increasingly associated with infrastructure facilities for tourists, while coral reef health and biodiversity are losing importance, associated with the decrease in sea-based activities. However, local residents take a stronger view on reef health than tourists.

Section 6.5 discusses the difficulties of establishing nonmarket value estimates for the Florida Keys to obtain a true total economic value. It highlights the difference between establishing project-based evaluations for reef management purposes, and developing an evaluation procedure that takes account of all stakeholder views on global climate change. The section concludes with elements of a possible approach to achieve this, basically replacing conventional willingness-to-pay measures with assessments based on greater scientific and economic knowledge than can be expected from survey respondents.

1.7 Scenarios

Section 7.1 describes how each of the four scenarios updated from the IPCC framework is treated in parallel seven-part descriptions in Sections 7.2 to 7.5. The last part of Section 7.1 (7.1.5) shows how the global scenarios were linked as formally as possible to the Florida Keys. The scenarios are the global economic growth-dominated A1, the global environmentally more sensitive B1, and the two regionalized scenarios A2 and B2, which are orientated towards economic growth and environmental considerations, respectively.

The seven-part descriptions of each scenario start with the original IPCC scenario, followed by a segment posing the question whether it would have been written differently in 2010, and a segment describing likely physical, economic and technological influences derived from the background papers (Hoegh-Guldberg 2010a,b,c,d). Part 4 links the present (2010) to the storyline to demonstrate the plausibility of the four scenarios – assuming the global storyline takes over from, say, the mid to late 2020s. Having established that this link is plausible, the scenario is then developed in Part 5 to the end of the century (with a little peep beyond). After a sketch of possible futures in the United States (Part 6), Part 7 zooms in on the Florida Keys with a set of standard projections and brief stories concluding each of the scenario descriptions. A graph shows the impact on the Keys from 2010 to 2100 according to four indicators: population, impact of sea-level rise, coral cover, and income relative to 2010.

Comparing each Part 7 on the Keys scenarios is important, especially the contrast between the global A1 scenario seen to be disastrous if allowed to run its full course, and the global B1 scenario which allows the area to remain viable despite a 38% inundation even under the most optimistic IPCC scenario by the end of the century (the two regionalized scenarios, A2 and B2, are each moderately more pessimistic than the corresponding global A1 and B2).

The final section, 7.6, displays a chart showing the comparison of the four scenario estimates for each of the four Florida Keys indicators. Common to all scenarios is declining population, coral cover and income, and rising sea level. However, the extent of the deterioration differs radically between the growth-driven "A" scenarios and the environmentally more sensitive "B" scenarios. The reason for these differences should be evident from the development of each scenario story from global to local level.

1.8 POLICY IMPLICATIONS AND RECOMMENDATIONS

The policy recommendations in Chapter 8 cannot be summarized and should be read in full. With climate change accelerating rapidly, the A1 path is disastrous and A2 even more so. B1 provides the best possibility though it still contains risks and its environmentally friendly approach needs further strengthening to bring the global temperature increase within the now required $2^{O}C$. The B2 scenario is less effective than B1 in preserving the Keys environment but features community involvement as a vital ingredient.

The following list is presented as a possible synthesis inspired by the specific findings of this research. It progresses from global to local perspectives:

1. There is overwhelming scientific consensus that climate change has become the most critically urgent issue of our time. There is an pressing need for effective international climate change mitigation now to limit the need to have to adapt in future.
2. Non-linear positive feedback responses in the climate system will become more frequent; intensified controlling action is urgently required. This is behind the targets to reduce greenhouse gas emissions by at least 80% by 2050, to stay below a $2^{O}C$ global temperature rise and 350 ppm CO_2. It is not just a matter for international negotiators; constant local, state and national action is required to reinforce and re-educate.
3. It is essential, therefore, to work toward an effective and binding international agreement on emissions control, with the onus on the developed world. Define substantial points for negotiation in time for the climate change conference in Mexico in December 2010 (COP-16) and achieve binding agreement for an effective successor to the Kyoto Protocol at the very latest at COP-17 in South Africa, in December 2011.
4. An environmentally friendly global scenario exemplified by the updated version of IPCC's "B1" is vital for long-term survival, backed by a prevailing spirit of strong community involvement. Continued encouragement of environmentally sensitive policies encompassing all nations is a primary objective, whatever it takes.
5. The political process in many leading countries has temporarily lost its sense of urgency and needs a wake-up call. The United States, as world leader, should ensure the passage of effective climate legislation through the Senate in 2010, but political reality suggests 2011. It must happen then.
6. It is high priority to promote and fund more research into new technologies including not only renewables but also energy efficiency and the protection of rural and coastal

carbon sinks, plus the international diffusion of all renewable technologies, big and small, to the developing world. Diffusion is important to get the whole planet involved.

7. The Florida Keys are the most threatened area in the most threatened mainland State in the nation. They would not survive in a "business-as-usual" scenario. This gives the Keys as a mainstream American community a unique voice in the advocacy.
8. The existing strength of the integrated coastal management philosophy forms a solid foundation for Keys-based action. The keyword is resilience.
9. Local government is an important part of the solution, setting local targets, coordinating local initiatives, pushing state and national action from "below", and generally helping to secure that the effort to build up resilience remains "climate-smart".
10. The Keys economy must remain viable if the community has any chance of thriving. Sixty percent of the economic activity comes from tourism, with no substitutes in sight. Tourist activity has been shifting from nature-based activities to historical tourism based on Key West. It is important to eliminate any dissonance between communities and induce maximum cooperation in their mutual interest.
11. Although mainly applied to the marine ecosystem centered on the coral reef, resilience is also a vital survival factor for other parts of the Florida Keys "super-ecosystem" – relating to natural areas, native species populations and human communities.
12. Structural change threatens the resilience of the human community in the Keys, with an influx of occasional visitors owning local property but having no other local interest. It is vital for survival to retain the strong current sense of community that remains. One way is keeping the young on side through education and outreach, encouraging them to stay, and to enlist their help working with and educating the older generation.

2 GLOBAL CHANGE

The outlook has changed greatly since the scenario storylines and emissions scenarios were constructed back in the second half of the 1990s (from even older information), and published in the Intergovernmental Panel on Climate Change *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) for the IPCC's Third Assessment Report (IPCC 2001). The changes have kept up since the scoping report for the current project was written (Hoegh-Guldberg 2005), so the basic global assumptions have had to be substantially revised and have therefore taken up more time than planned when the project was first undertaken.

This is documented in four background papers (Hoegh-Guldberg 2010a,b,c,d) which should be read for full understanding of the findings for the Florida Keys (in addition to Appendices 1 and 2 which deal with the local issues in the Keys). The global outlook has become more important and more complex over the past decade and has to be the starting point of any analysis of the local impact of climate change.

The four global background papers are summarized below. They represent a departure from the design of the Great Barrier Reef report (Hoegh-Guldberg and Hoegh-Guldberg 2004) which was the intended template for the current project. Each background paper was developed for a specific purpose to back the main report, and have their own reference sections.

2.1 RISKIER SCENARIOS

The IPCC's Fourth Assessment Report (Pachauri and Reisinger 2007) officially recognized that the causes for concern identified in the previous report (IPCC 2001) had become generally more serious. Since 2007, the outlook has deteriorated further, which is one of two main reasons for a veritable flood of new references to climate change during 2009. The second reason was the COP-15 climate change conference in Copenhagen, Denmark, in December.

The question is how the changed outlook should be reflected in the global scenario storylines, in the emissions scenarios associated with each storyline, and what are the socioeconomic implications?

The storylines themselves are sufficiently general to incorporate most changes, especially the global scenarios A1 and B1. The storylines for regional scenarios A2 and B2 are more out-of-date. This is reflected in the presentation of each scenario in Chapter 6.

Hoegh-Guldberg (2010a) provides a broad review of the development of findings between the Third and Fourth IPCC Assessment Reports, with reference to possible changes to the use of scenario planning in the forthcoming Fifth Assessment Report, due in 2014 (Moss et al. 2008). The latter may take a new tack, in which mitigation strategies against the risks are apparently capable of being built into the scenarios themselves. This would be different from or at least supplementary to the current scenarios, which run to the "bitter end" to demonstrate the effects of not taking additional action during the course of the scenario period.

Climate change will disadvantage poor countries in particular. "The two greatest problems of our times – overcoming poverty in the developing world and combating climate change – are inextricably linked." (Stern 2009, p 8) The United Nations Millennium Project is important because of its ongoing monitoring of global and regional socioeconomic indicators with a focus on low-income countries. The 2008 *State of the Future Report* (Glenn et al. 2008) halfway through the 15-year project declared that humanity is "winning" on life expectancy, infant mortality, literacy, GDP per person, conflicts, and Internet use, but targets are not being met on CO_2 emissions and global warming, terrorism, corruption, voting populations, and unemployment (Gordon 2007).

Among the sources quoted in Hoegh-Guldberg (2010a), none is more comprehensive than *Six Degrees*, by British science writer Mark Lynas (2008). Describing worlds emerging as the average temperature rises by one and then two, three, four, five and six degrees Celsius, he demonstrates on the basis of a comprehensive survey of the scientific literature existing in 2007 how ecosystems have already been affected while the temperature has risen by less than 1^{O}C (notably coral reefs), how the scenario is likely to take on nightmare proportions at or before +4 ^{O}C, and how positive feedback effects in the climate system may accelerate changes in global temperature after the average warming reaches the 2-3^{O}C range.

Major economic treatises from the UK, Australia and America weigh in with other ominous predictions if the world continues along a "business-as-usual" path, and therefore urge concerted policy action to avoid such outcomes (Stern 2006 and 2009, Garnaut 2008, Sachs 2008). It is also either stated (Meinshausen 2004, Stern 2006) or implicit in the analysis of uncertainties in the climate models that the cost of tackling climate change will escalate the longer action is delayed (Meinshausen et al. 2009).

The director of NASA's Goddard Institute for Space Studies, James Hansen, was the first to push for atmospheric CO_2 to be reduced to 350 ppm or less, to be *reasonably* sure that the planet's average temperature increase remains within a *reasonably* safe 2^{O}C. Other advocates described in the last main section of Hoegh-Guldberg (2010a) dealing with the need to set a <350 ppm target include Spratt and Sutton (*Climate Code Red*, 2008). They identify the heart of the climate change problem as the melting of the Arctic sea-ice, which they maintain can be reversed only by lowering atmospheric CO_2 levels to 300-325 ppm.

There was such a strong movement during 2009 in favor of a reduction to <350 ppm that it became the new position taken by scientists (supported by campaigners like *350.org*, who organized a successful global series of demonstrations for "World Climate Day" on October 24). There is increasing agreement that this position is required for humanity to have a reasonable chance of keeping global warming within 2^{O}C of the pre-industrial level.

The final paper reviewed in Hoegh-Guldberg (2010a) urges the reduction of CO_2 levels below 350 ppm. Veron et al. (2009) was written by a group of prominent coral reef scientists, describing the cumulative impact of rising sea temperatures on coral bleaching over the past 40 years, and how the more recently recognized threat from ocean acidification is exacerbating the situation. The paper points to probable domino effects, not only to neighboring ecosystems such as seagrasses and mangroves, but across the oceans as all carbonate-dependent taxa become affected by the acidification process.

Refer Hoegh-Guldberg (2010b) for a discussion of possible reductions in economic projections as the planet warms in the less environmentally sensitive scenarios, and Hoegh-

Guldberg (2010c) for the estimated impact of events since late 2008: the global economic crisis, political rejection of emissions trading or cap-and-trade schemes, and the indifferent outcome of the climate conference in Copenhagen in December 2009.

2.2 LIMITS TO GROWTH

Many scientists and economists have pointed to the dire consequences of "business-as-usual" scenarios, but no attempt to quantify these predictions has been found. The IPCC scenarios themselves make no connection between a rapidly warming planet and its ability to support continuing economic growth – none of the four scenario families assumes that the connection exists. The fossil-intensive high-global-growth scenario variant, A1FI, is often used as a "business-as-usual" proxy (which is actually incorrect in scenario-planning terms). Like other IPCC scenarios showing significant global warming, it contains an implicit assumption that new technology will protect all of humankind from the effect of temperatures soaring to 3^{O}C and more above pre-industrial levels.

There is a critical associated problem which we are stuck with for now: the scenarios use conventional economic growth measures which take no account of the depletion of resources. It is not simply non-renewable resources such as mineral deposits that are depleted (in principle these can be measured as normal statistics) – it is also the atmosphere and the world's ecosystems. The need to allow for these is great, but they cannot be expressed as conventional national accounts data.

A report commissioned by French President Nicolas Sarkozy, by Nobel Prize-winning economists Joseph Stiglitz and Amartya Sen and their French colleague Jean-Pierre Fitoussi, represents a major approach to tackle these issues (Stiglitz et al. 2009). Long before, *Genuine Progress Indicators* were developed for the United States and various European countries in the 1990s to try and account for social and environmental constraints to the planet's economic growth. The American GPI shows a steadily growing gap below the conventional GDP between 1950 and 1995, and a significant decline in the GPI since the early 1970s (Victor 2010). If the growing threat from climate change can be adequately measured in an revived GPI, the gap is likely to be considerably wider in 2010. The initiative by Stiglitz, Sen and Fitoussi may spark the development of an superior measure.

Probability analysis continues to indicate considerable uncertainty in estimating climatic changes resulting from greenhouse gas emissions, and we are consequently facing increasing risks as atmospheric CO_2 levels rise. Harvard economist Martin Weitzman (2009) warns that the risk of extreme climate-related events has been rising – what he calls the "fat tail" of the probability distribution. Stern (2009) also warns against the rising danger of extreme temperature levels as stabilization levels for greenhouse gases increase.

As indicated in the first paragraph, no one seems to have quantified this, only predicted that "business-as-usual" could bring disaster. But compared with the IPPC's economic growth projections for the end of the century, which range between $235 trillion at 1990 dollar values for scenario B2 and $530 billion for the three A1 scenarios – what does "disaster" mean? Reducing global GDP by 90% at +6^{O}C still leaves A1 higher than the $40 trillion or so in 2010, for roughly the same global population of seven billion. The base case put forward in Hoegh-Guldberg (2010b) is that global GDP reduction compared with the IPPC projections kicks in at +1.5^{O}C, and gradually reaches a 5% cut at +2 ^{O}C, -50% at +4^{O}C, and -90% at +6^{O}C.

Any reduction from "what might have been" will probably always be termed a disaster, partly because economic growth has become a fetish, and also because the loss will be inequitably borne by some countries, regions and population groups rather than others. If it ever happened, however, the feeling of disaster would be exacerbated by the path of economic change, especially if the global GDP runs into long-term decline. As we are currently witnessing, economic downturns focus the public and political mind like very little else – certainly more than the threat from climate change did in 2009.

The analysis in Hoegh-Guldberg (2010b) covers the four main IPCC scenarios: A1B (globalized economic growth orientation with balanced fossil and renewable power technologies), A2 (regional growth orientation), B1 (global environmental orientation), and B2 (regional environmental orientation). In addition to the intermediate A1B "marker scenario" listed above, the A1 analysis also includes its variants: A1FI (fossil-intensive) and A1T (renewables take over).

The three cases are based on Table 3.1 in the 2007 IPCC report (Pachauri and Reisinger 2007) showing the range between best and worst case projections, and the "most likely" case in between. In the "best case", with the smallest increase in warming, all six scenarios show continued growth, not drastically below the unmodified IPCC projections, but in the "most likely" case the fossil-intensive A1FI starts falling from 2080, and in the "worst case" all but one of the scenarios show economic decline: A1FI from the 2050s, A2 from 2060, the marker growth scenario A1B and B2 from 2080, and even the environmentally friendliest global growth scenario, A1T, from 2090. The *only* scenario passing the *worst case* with uninterrupted growth through the century is the global environmentally sensitive B1. Consequently, it is also the scenario least affected compared with the original estimates, showing about 20% reduction from the $328 trillion projected by the IPCC, to a level almost seven times the 2010 world GDP (which is estimated at around $38 trillion in 1990 prices).

Hoegh-Guldberg (2010b) discusses the approach and gives numerical details. It also contains sensitivity analysis indicating that the basic findings stand, although naturally the detail and the methodology would benefit from more refined analysis. There is no pretence that this is more than a preliminary numerical estimate where none appears to have been made before.

2.3 CHANGING ECONOMIC PHILOSOPHY

Before the United States and the rest of the world were hit with the global financial crisis, finally triggered by the Lehman Brothers collapse in September 2008, there was a growing realization that macroeconomic theory and policies were proving inadequate. When Nicholas Stern published his *Review on the Economics of Climate Change* in October 2006, he declared greenhouse gas emissions to be the greatest *market failure* the world has known.

Economic theory associates market failure with *externalities* – transactions which have a negative impact on parties not directly involved in the transaction are defined as market failure; and with *public goods*, which can be consumed by one individual without reducing its availability to others. In traditional economic theory, the atmosphere remains a public or free good despite years of campaigning by environmental groups and others; the same applies to numerous ecosystems that are difficult or impossible to value in market terms.

Next, the current economic crisis, incredibly, struck without apparent warning despite some quite extreme behavior patterns in the banking system, housing finance sector, and Wall Street – as has been exhaustively debated since the crisis hit and spread to the rest of the world. The main response has been to blame neoclassical economic theory which provided the dominant philosophy for policy-makers during the 30 years preceding the crisis.

John Maynard Keynes, in *The General Theory of Employment, Interest and Money* (1936) identified the behavior of investors as the one component of his theoretical framework that could show destabilizing "irrational" elements if not controlled, by magnifying the fluctuations in stock prices and other financial indicators way beyond what was compatible with true economic values – what he called *animal spirits.* This is also the title of a book by Nobel Prize-winning economist George Akerlof and Yale economics professor Robert Shiller (2009). They identify five psychological traits, or manifestations of animal spirits, which came to dominate the financial markets: *confidence*, *fairness*, *corruption and antisocial behavior*, *money illusion*, and *stories* (fully explained in Hoegh-Guldberg 2010c).

The question remains: How did this happen? In a nutshell, economists following in Keynes's footsteps as early as the 1930s and 1940s forgot his animal spirits, which got crowded out by a vogue for mathematical economics and econometric models that fitted well with the rest of the Keynesian model based on "rational" economic behavior. Add to this a political philosophy growing strongly from the late 1970s and early 1980s that free markets were best left alone to kick the economy along, and the path towards the financial crisis was set.

There was another growing influence besides the recognition that the economics of climate change was not being well accommodated in the current macroeconomic thinking, and the influence of Keynes's "economically irrational" animal spirits wasn't either. That was the advent of interdisciplinary "complexity theory" mainly through the Santa Fe Institute in New Mexico, and the early role of economics in that development, throughout which the multi-skilled economist W. Brian Arthur has figured prominently as described in Hoegh-Guldberg (2010c).

The main features of complexity economics (apart from involving economics in entering into closer collaboration with other disciplines) include open, dynamic, nonlinear systems, an evolutionary process of differentiation, selection and amplification providing the system with novelty, technological change generated within the system, and a fluid "biological" approach replacing a rigid 19th and early-to-mid 20th century "physics-based" preoccupation with equilibrium, stability, and determinism (Beinhocker 2006, Arthur 2000). The differences from the traditional economic model are profound (Hoegh-Guldberg 2010c, Figure 4).

Looking ahead, it is likely that economics will change, at least as far as to reflect its failure to predict the irrational behavior of the financial markets that led to the crisis. The economics of climate change, however, is also concerned with "animal spirits"; the market failure called greenhouse gas emissions originated in the 18th century. Animal spirits profoundly influenced the technological battle between gasoline and electricity for automobiles a century ago (Black 2006). Economics is also likely to be influenced by its association with other social and physical sciences in the framework of complexity theory.

The events since the financial crisis first began to affect the American economy became international with the collapse of Lehman Brothers in October 2008. This added a final dimension to the interpretation of contemporary economics, and how it may change. The economic crisis has coincided with the climate scientists becoming increasingly insistent on political action as the climate change signals called for greater urgency, whereas the public and political perception has gone in the opposite direction as short-term economic and financial considerations resumed the main stage and climate change denial became the name of the game for many. This is discussed at the end of Hoegh-Guldberg (2010c).

The crucial requirement according to most climate scientists and other experts is to tighten the emissions scenarios. The scientific consensus is now dominant that the world can no longer run the risk of planning for a $3^{O}C$ increase of the global average air temperature, consistent with targeting atmospheric CO_2 levels at 450 ppm or more. It is also abundantly clear that climate models produce variable results, and that even those indicating a mean increase of $2^{O}C$ carry risks that the rise will be higher. The uncertainty widens as the mean temperature increases, which renders the previous typical $3^{O}C$ target even more untenable.

The uncertainty calls for urgent rather than delayed (or no) action. Dismissing the evidence because the climate models contain uncertainties goes against any actuarial principles of risk assessment.

Fortunately, the Copenhagen Accord that concluded the COP-15 conference in December 2009 acknowledged, for the first time in an official international document, that a maximum $2^{O}C$ increase above pre-industrial levels is appropriate. The corollary is that atmospheric CO_2 levels should be reduced to 350 ppm or less, not increased to higher stabilization levels.

The socioeconomic implications of the recent change in outlook vary from drastic to tolerable, prompting scientists to campaign more forcefully than ever for a heightened sense of urgency among politicians (Richardson et al. 2009). This is being reflected in actual climate change policy but only with a time lag, as illustrated by the failure of the US Administration to get its cap-and-trade bill through Congress, with opposition politicians being supported, indeed urged on to resist such legislation by a public that became more prone to outright denial, not just skepticism, about the existence of climate change in 2009.

Universal cap-and-trade schemes actually may have become so politically unacceptable in the United States and elsewhere that they may be replaced with arrangements to target specific sectors or individual industries. There are exactly four general ways to control carbon: reducing either population, GDP per head of population, energy intensity (energy used per unit of GDP), or carbon intensity (CO_2 per unit of GDP). The first two are considered to be politically unachievable within a realistic timeframe, leaving improvements in energy efficiency (less energy per unit of GDP) and reduced carbon intensity as the main avenues to follow. Both are associated with technological change (see Hoegh-Guldberg 2010d).

Given that economic theory has been an important influence on government financial and economic policy to date, it is plausible to expect this to continue in the future, including what has happened since late 2008. But the influence on economic policy will differ in the four scenarios, which is why the findings in the third background paper (Hoegh-Guldberg 2010c) are critical for the scenario building.

2.4 WHAT CAN WE ASSUME ABOUT TECHNOLOGICAL CHANGE?

A driving force in complexity economics and member of the Santa Fe Institute, W. Brian Arthur, is the author of *The Nature of Technology* (2009), which provided the inspiration and theme for Hoegh-Guldberg (2010d). The publication of Arthur's book coincides with a rising interest in innovation among the social sciences (Fagerberg and Verspagen 2009), including a renewed appreciation of Austrian-American economist Joseph Schumpeter (1883-1950), who maintained that technology is generated *within* the economic system – in contrast to the assumption usually made in neoclassical economics. Arthur's book develops the theory of endogenously generated technological change (with more than a nod towards Schumpeter), leading to *increasing* rates of return in a dynamically changing economic system, whereas the static neoclassical economic model shows decreasing returns.

Brian Arthur's model explains technology as a continuous, organically evolving process which bears a strong resemblance to Darwin's theory of evolution (though the selection process has to be different). Innovation doesn't arise out of thin air but is *always* based on current technology, and once an innovation is adopted, it gives rise to further change involving a hierarchy of underlying technologies. The whole pattern is subject to continuing evolution and has to keep fitting in with this evolution in conditions of constant dynamic change.

A World Bank analysis (Burns et al. 2008) found that the primary influence on technological growth, innovative and inventive activity, has been strongly concentrated in the richest countries. But it also found that new technologies are imported and adopted into the entire developing world, including the least developed nations, and at increasing speed. The evidence is strengthening that the World Bank report is becoming rapidly outdated if it ever got the message right in the first place – genuine innovation (as distinct from technologies imported from the rich countries) is swiftly becoming more prevalent (Wooldridge 2010).

It fits Arthur's model that developing countries are moving on into real innovative activities of their own: new technology may be initially imported but it will then be refined and adapted to particular applications within the countries themselves, and eventually lead to genuine innovations originating there. The result should be an expansion of the genuinely inventive base of the planet, from the richest countries through upper- and even lower-middle-income countries as we see today in Brazil and Thailand, and in the richer urban regions of China and India. Of course, it may take a long time before significant real innovative activity as distinct from importing other countries' technologies will reach the least developed countries such as Sub-Saharan Africa.

The review of technologies (Hoegh-Guldberg 2010d) comprises three groups: energy technologies including renewable sources such as solar, wind, geothermal, hydro, and oceanic, plus nuclear energy (fission, fusion, and hybrid); a wide range of energy efficiency technologies of which the main one is efficient building design; and land and coastal management technologies aiming at preserving and improving carbon sinks. "Green carbon" technologies are based on forestry and agricultural activities which may not look as spectacular as the first group but may have profound effects because of their ability to be adopted in poor as well as rich nations and at small as well as large scale – furthermore biotechnology is currently advancing fast in support of these technologies, as well as becoming better accepted. “Blue carbon” coastal management technologies serve to protect mangroves, seagrasses, and salt marshes which play a vital role through their photosynthetic activities in transferring CO_2 into long-term storage in the deep ocean (Nellemann et al. 2009).

The findings by Hoegh-Guldberg (2010d) support the statement in the *Special Report on Emissions Scenarios* (Nakicenovic and Swart 2000) that technology is a main driving force of these scenarios coupled with demographic change and economic development. However, there is no single-solution “silver bullet” allowing humanity to switch from fossil-fuel to renewable-energy technologies (Pacala and Socolow 2004). Each SRES-based scenario will of course have distinctly different combinations of technologies depending on the general storyline.

Two further points should be made. First, despite the apparent current interest of some governments and a large increase in the number of research papers on these technologies (*The Economist* 2010b), large geoengineering “solutions” to the global warming problem noted in Hoegh-Guldberg (2010d) are largely dismissed, mainly because they are highly risky environmentally. In their current undeveloped state they also represent, at most, steps towards mitigation, which are not supposed to be part of the scenarios. One possible technology among these options would be seeding the stratosphere with sulfur particles to deflect incoming sunlight back into space (Crutzen 2006) – but it is fraught with risks according to the main Royal Society analysis of geoengineering options (Shepherd et al. 2009). In short, options that can be grouped as geoengineering in the sense of significant manipulation of nature are not part of the scenarios (despite the proliferating research).

The second point, however, is of vital importance for the understanding of climate scenarios. It reflects Stern’s (2009) observation, quoted in Section 2.1, that climate change and poverty are inextricably linked. It is observed in the final sections of Hoegh-Guldberg (2010d) that as well as directing the attention towards specific renewable energy technologies and particular scales of applying these technologies, beating the poverty trap also means encouraging other technologies with which the climate-related technologies interact. The introduction of microcredit in the least developed countries (starting in Bangladesh) and the current rapid adoption of cell phone and cheap computer technology are current examples, but there will be others which are likely to vary considerably between countries.

3 NATIONAL AND REGIONAL US PERSPECTIVES

3.1 LINKING GLOBAL AND LOCAL SCENARIO BUILDING

The four background papers summarized in Chapter 2 are global in scope. The first step toward the linking of global and local perspectives is to take a nationwide view of the United States. Then relevant regional differences and prospects within the nation can be explored, focusing on the Southeast along the Gulf of Mexico and the southern Atlantic coast as the final link to the Florida Keys.

Whether the scope of the perspective is global, regional, or local, these chapters concentrate on the physical evidence rather than the political, economic and commercial issues associated with climate change. It is abundantly clear from the experience of the past decade or more that the relationship between the mounting scientific evidence for accelerating climate change and the politics has fluctuated – to put it mildly. In 2009, the scientific and political paths diverged quite sharply – in 2010 there are conflicting signs as to whether the tendency is again towards convergence.

General acceptance of the urgency to tackle climate change continues to be blurred by conflicting communications and the complexity of intergovernmental and international infrastructures. For example, it is a promising sign that a majority of states (including Florida) have adopted more or less stringent, but binding, renewable portfolio standards to mandate the introduction of renewable energy, while such a standard is not visible at federal level. "Though a national policy would be nice, 50 state policies may turn about to be even better. This way, they can tailor their requirements to available resources." (Hodge 2010) Internationally, China is torn between its dependence on expanding coal-based technology and the realization that it is environmentally highly fragile. And so on.

The role of the scenario analysis in Chapter 7 is to outline different futures which highlight the risks and opportunities associated with different sets of policies, basically divided between growth-driven "business-as-usual" and environmentally friendly scenarios.

A US Global Change Research Program report (Karl et al. 2009) was transmitted to Congress by the Director of the Office of Science and Technology Policy, Dr John Holdren, and NOAA's Administrator Dr Jane Lubchenko. This was only the second such report, following nine years after the first one (Melillo et al. 2000). It contains a powerful chapter on the severity of global climate change prefaced by a graph of Antarctic ice-core data showing that atmospheric CO_2 never exceeded 300 parts per million for 800,000 years, but is now 30% higher than the geological-time maximum. Having grown slowly from pre-industrial levels it then started to accelerate from about 310 ppm in the late 1960s to reach the current level, increasing annually by about 2 ppm.

The global findings (Karl et al. 2009, p 12) resemble those compiled for the current project: global warming is unequivocal and primarily human-induced, and widespread climate-related impacts are occurring now that are expected to increase, affecting water, transportation, agriculture, ecosystems, and health.

The report describes national climate change and then presents a regional analysis of vulnerabilities to climate change within the United States, showing that the climate is already changing wherever we look. The following salient points were extracted from the summary (Karl et al. 2009, p 27):

- The average temperature has risen more than 2^{O}F (more than 1.1^{O}C) over the past 50 years (above the global average of 0.74^{O}C for the 100 years from 1906 to 2005) and is projected to rise more in the future. Using the original A2 scenario (Nakicenovic and Swart 2000) yields a projected temperature increase of 7-11^{O}F (3.8-6.1^{O}C) over the 21st century, and 4-6.5^{O}F (2.2-3.6^{O}C) using the global environmental scenario B1.

  The authors add that using a stabilization scenario of 450 ppm CO_2 has the potential of keeping the global temperature rise at or below about 3.5^{O}F (1.9^{O}C) from pre-industrial levels and 2°F (1.1^{O}F) above the current average temperature, "a level beyond which many concerns have been raised about dangerous human interference with the climate system." (Karl et al. 2009, pp 23-24) However, the references are two Meinshausen papers, both dated 2006. A stabilization level of 450 ppm is now considered incompatible with a 2 ^{O}C rise above pre-industrial levels, and Meinshausen (from the Potsdam Institute of Climate Impact Research) has co-written more recent papers, including one shown in our references dated 2009.

- Projections of future US precipitation indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier. More rain is falling in heavy downpours (an average increase of about 20% in the past century, a trend that is deemed very likely to continue, with the largest increases in the wettest places).

- Extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.

- The destructive energy of Atlantic hurricanes has increased in recent decades. The intensity of these storms is likely to increase in this century.

- The sea level has risen along most of the US coast over the last 50 years, and will rise more in the future. Arctic sea-ice is declining rapidly and this is very likely to continue.

3.2 SHARED REGIONAL VULNERABILITIES

The United States is divided into eight regions: Northeast, Southeast, Midwest, Great Plains, Southwest, Northwest, Alaska, and Islands (Karl et al. 2009, pp 107-148). The islands are located in the Pacific including Hawaii, American Samoa, Palau, and the Micronesian Carolinas, Marshalls and Marianas, and in the Caribbean: US Virgin Islands and Puerto Rico under the US, not counting 40 island nations with 38 million people which share similar conditions – indeed these countries are expected to be among the earliest and most impacted by climate change in the coming decades and are least able to adapt to climate change (Simpson et al. 2009, p 8).

3.2.1 COASTS

The regional analysis concludes with a review of coastal areas (pp 149-152) which is most directly relevant for this project. A summary follows:

- Approximately one-third of Americans live in counties immediately bordering the nation's ocean coasts. Coastal and ocean activities contribute more than $1 trillion to GDP and ecosystems hold rich biodiversity and provide invaluable services.
- Intensive human use has taken its toll on coastal environments and their resources, through overfishing, the expansion of major cities and their infrastructures, and agriculture, shipping, tourism and other economic activities. More spring runoff and warmer coastal waters cause seasonal reduction in oxygen resulting from excess nitrogen from agriculture, helping to create dead zones depleted of oxygen. As well as adding nitrogen, coastal waters are polluted by phosphorus, sediments, and numerous other contaminants. Toxic blooms of algae are also becoming more frequent.
- Coral reefs have been badly damaged or are becoming overgrown with algae. Higher water temperatures and ocean acidification resulting from the uptake of carbon dioxide by ocean waters will present major additional stresses to coral reefs, resulting in significant die-offs and limited recovery. Acidification imposes yet another stress on reef-building corals, which already suffer from bleaching, disease, coastal runoff and other pollution. "As a result of this and other stresses, the corals that form the reefs in the Florida Keys, Puerto Rico, Hawaii, and the Pacific Islands are projected to be lost if carbon dioxide concentrations continue to rise at their annual rate."
- The increasing acidification threatens not only corals, but shellfish and other living organisms that form their shells and skeletons from calcium carbonate.
- Half the nation's coastal wetlands have been lost, mainly during the past 50 years.
- Sea-level rise and storm surge affect coastal cities and ecosystems; low-lying and subsiding areas are naturally most vulnerable. Coastal areas are at increasing risk from sea-level rise and storm surge, especially along the Atlantic and Gulf Coasts, parts of Alaska, and islands in the Pacific and Caribbean. Energy and transportation infrastructure are very likely to be adversely affected. Furthermore, thresholds will be crossed, leading to large changes in climate and ecosystems.
- Changing ocean currents will affect coastal ecosystems.
- Generally, climate change combined with pollution, population growth, overuse of resources, urbanization, and other social, economic and environmental stresses will create larger impacts than from any of these factors alone.

Surprisingly, the second assessment report (Karl et al. 2009) makes little or no mention of the first report (Melillo et al. 2000), although Thomas Karl and Jerry Melillo were co-chairs of both. The first report gives a valuable historical perspective on how the assessment of climate change has developed, and provides additional information which presumably remains valid in 2010. It shows that issues considered urgent today were recognized a decade ago by the leading American scientists involved in this research. The following points from the 2000 report relate to the coastal zone which is our central concern.

- **Sea-level rise**: "Global sea level has already risen by 4 to 8 inches (10-20 cm) in the past century, and models suggest this rise is very likely to accelerate. The best estimate is that sea level will rise by an additional 19 inches (48 cm) by 2100 with an uncertainty range of 5 to 37 inches (13-95 cm). Geological forces (such as subsidence, in which the land falls relative to sea level) play a prominent role in regional sea-level change. Accelerated global sea-level rise is expected to have dramatic impacts on those regions where subsidence and erosion already exist." (p 108).

The assessment of causes seems to have shifted from geological forces to external factors including melting Arctic ice, but sea-level rise was evidently considered a main factor in 2000. It was rated urgent then and even more so now.

- **Coastal lands at risk**: Eighty percent of all coastal wetlands (marshes and mangroves) in the US is in Louisiana, and the rest mainly along the rest of the Mexican Gulf and the Atlantic coast. In the event of a 20-inch sea-level rise, the table to the left shows Louisiana way ahead of other coastal regions concerning both wetland and dryland areas risking inundation. The numbers are estimates only, read off the published chart. Since the table was constructed for this report, the Deepwater Horizon oil spill disaster in May 2010 took place immediately off the coast of Louisiana.

Coastal lands at risk from a 20-inch sea-level rise (square miles, estimated from graph)		
Region	**Wetlands**	**Dryland**
Northeast	~100	~100
Mid-Atlantic	~200	~700
South Atlantic	~1,200	~900
S to W Florida	~100	~600
Louisiana	~2,200	~1,200
Rest of Gulf Coast	~400	~600
West	~-200	~300
Source: Melillo et al. (2000, p 110)		

- **Coral reefs affected by bleaching, disease, pollution, and ocean acidification**: "The last few years have seen unprecedented declines in the health of coral reefs. The 1998 El Niño was associated with record sea-surface temperatures and associated coral bleaching (when coral expels the algae that live within them and are necessary to their survival); in some regions, as much as 70% of the coral may have died in a single season. There has also been an upsurge in the variety, incidence, and virulence of coral diseases in recent years, with major die-offs in Florida and most of the Caribbean region. In addition, increasing atmospheric CO_2 concentrations could possibly decrease the calcification risks of the reef-building corals, resulting in weaker skeletons, reduced growth rates and increased vulnerability to erosion. Model results suggest that these effects would likely be most severe at the current margins of coral reef distribution." (p 111) The Keys are located just within those margins.

  "Note that under model projections of the future, it is very unlikely that calcium carbonate saturation levels will provide fully adequate support for coral reefs in any US waters. The possibility of this future scenario occurring demands continued research on effects of increasing CO_2 on entire coral reef systems." (p 112)

  A map on the same page (reprinted in the 2009 report, p 151) shows carbonate saturation levels measured in ohm (Ω) in American ocean surface waters. It identifies the level in pre-industrial Florida as "optimal" (>4 Ω), and the level in 2000 remained optimal on the Atlantic side but dropped to "adequate" (3.5-4 Ω) on the western side. The projection for 2050 for the whole of Florida drops to "marginal" (3-3.5 Ω). The projection also shows a drop to "extremely low" (<3 Ω) for the coastal waters – largely devoid of coral reefs – from Florida's "panhandle" further west into the Gulf.

The description of coral reefs was made shortly after the El Niño bleaching events in 1998, and contains plenty of references to this, plus the key statement: "Some estimates of the global cost of losing coral reefs run in the hundreds of billions of dollars each year. The demise or continued deterioration of reefs could have profound implications for the US." (p 111)

The reference to ocean acidification in a publication as early as 2000 was a surprise and worth considering in a current context. Papers published before 2000 usually "did not consider the carbonate chemistry of seawater .. to be an important factor influencing calcium-carbonate precipitation by corals because surface seawater is supersaturated with respect to aragonite." (Gattuso et al. 1998) More recent papers like Fabry et al. (2008) suggest that the main research papers on ocean acidification as a threat to reef-building corals and other organisms date from about 2004 up to date.

The latest contribution at the time of writing, dealing with ocean acidification generally and not just confined to coral reefs, is Pelejero et al. (2010), containing the phrase that acidification is "the evil twin of global warming". The message just keeps getting more urgent. The abstract tells it all: "Anthropogenic rise in atmospheric CO_2 is driving fundamental and unprecedented changes in the chemistry of the oceans. This has led to changes in the physiology of a wide variety of marine organisms and, consequently, the ecology of the ocean. This review explores recent advances in our understanding of ocean acidification with a particular emphasis on past changes to ocean chemistry and what they can tell us about present and future changes. We argue that ocean conditions are already more extreme than those experienced by marine organisms and ecosystems for millions of years, emphasizing the urgent need to adopt policies that drastically reduce CO_2 emissions."

However, the seminal research paper on the threat from ocean acidification by Joan Kleypas and colleagues was published as early as 1999 (Ove Hoegh-Guldberg, personal communication). It established that since a coral reef represents the net accumulation of calcium carbonate ($CaCO_3$) produced by corals and other calcifying organisms, reef-building capacity declines if calcification declines. Coral reef calcification depends on the saturation state of the carbonate mineral aragonite in surface waters. The authors predicted then that the total calcification reduction from the pre-industrial level to 2100 could be as high as 17 to 35%.

- **Coastal erosion**: The last point to mention from the first assessment report concerns coastal management. "With few exceptions, the potential consequences of climate change are not yet being considered in coastal management. It is especially urgent to begin adaptation now with regard to development of land in the coastal zone." (Melillo et al. 2000, p 113)

  A map of annual shoreline change, also on p 113, carries the following comment: "The areas most vulnerable to future sea-level change are those with low relief which are already experiencing rapid erosion rates, such as the Southeast and Gulf Coast." The map shows the Florida Keys as "moderately eroding" (similar to the rest of Florida apart from six relatively small areas rated "severely eroding"). In contrast, the entire shoreline along the States of Louisiana and Mississippi was classified as "severely eroding".

We note again that our comments on Melillo et al. (2000) were written before the Deepwater Horizon oil spill off Louisiana in May 2010. Containing 80% of the nation's wetlands, this coastline has been considered highly vulnerable for a long time.

3.2.2 THE SOUTHEAST AND CHARACTERISTICS SHARED WITH OTHER REGIONS

The Southeast region covers the coast from Texas (the rest of that State is part of the Southwest region) along the Gulf via Florida and up the Atlantic coast to Virginia. The Southeast extends inland as far as Arkansas, but the coastal character dominates the description in the second US Global Change Research Program report (Karl et al. 2009).

A condensed version of the threat of climate change in the Southeast reads as follows (pp 111-116): Since 1970, the annual average temperature has risen about 2°F (1.1 ^{O}C), with the greatest seasonal increase during the winter months. The number of days per year with 90^{O}F (32^{O}C) or over will increase toward 180 or half the year, resulting in heat stress for people, plants and animals. The availability of water will decrease. Sea-level rise and hurricane activity will be among the most serious climate change effects. Ecological thresholds are expected to be crossed throughout the region leading to disruption of major ecosystems and the benefits they convey to people. Quality of life will be affected by heat stress, water scarcity, severe weather events and reduced availability of insurance to properties at risk.

The regional analysis in the report shows that among the attributes of climate change, water availability and drought, warmer temperatures, and impact on ecosystems will have universal, or almost universal, impact across the nation. Water scarcity and hotter weather will be grave concerns for the Southeast, and the region is among the most seriously affected by the threat of sea-level rise, increasing frequency and severity of hurricanes and storm surges, and impact on ecosystems. The region's coral reefs are especially vulnerable to bleaching and disease, in common with the rest of the Caribbean and the Pacific, due to warmer sea temperatures and ocean acidification.

Of the key points made in the report, two in particular deserve mention in a Florida Keys context:

Sea-level rise and the likely increase in hurricane intensity and associated storm surge will be among the most serious consequences of climate change . (Karl et al. 2009, p 114)

"As sea level rises, coastal shorelines will retreat. Wetlands will be inundated and eroded away, and low-lying areas including some communities will be inundated more frequently – some permanently – by the advancing sea. Current buildings and infrastructure were not designed to withstand the intensity of the projected storm surge, which would cause catastrophic damage. .. More frequent storm surge flooding and permanent inundation of coastal ecosystems and communities is likely in some low-lying areas .. . Rapid acceleration in the rate of .. sea-level rise could threaten a large portion of the Southeast coastal zone. The likelihood of a catastrophic increase in the rate of sea-level rise is dependent upon ice sheet response to warming, which is the subject of much scientific uncertainty. Such rapid rise in sea level is likely to result in the destruction of barrier islands and wetlands.

Compared to the present coastal situation, for which vulnerability is quite high, an increase in hurricane intensity will further affect low-lying coastal ecosystems and coastal communities along the Gulf and South Atlantic coastal margin. An increase in intensity is very likely to increase inland and coastal flooding, coastal erosion rates, wind damage to coastal forests, and wetland loss. Major hurricanes also pose a severe risk to people, personal property, and public infrastructure in the Southeast, and this risk is likely to be exacerbated. Hurricanes have their greatest impact at the coastal margin where they make landfall, causing storm surge, severe beach erosion, inland flooding, and wind-related casualties for both cultural and natural resources."

Ecological thresholds are expected to be crossed throughout the region, causing major disruptions to ecosystems and to the benefits they provide to people. (pp 115-116)

"Ecological systems provide numerous important services that have high economic and cultural value in the Southeast. Ecological effects cascade among both living and physical systems, as illustrated in the following examples of ecological disturbances that result in abrupt responses, as opposed to gradual and proportional responses to warming:

- The sudden loss of coastal landforms that serve as a storm-surge barrier for natural resources and as a homeland for coastal communities (such as in a major hurricane).
- An increase in sea level can have no apparent effect until an elevation is reached that allows widespread, rapid saltwater intrusion into coastal forests and freshwater aquifers.
- Lower soil moisture and higher temperatures leading to intense wildfires or pest outbreaks (such as the southern pine beetle) in southeastern forests; intense droughts leading to the drying of lakes, ponds, and wetlands; and the local or global extinction of riparian and aquatic species.
- A precipitous decline of wetland-dependent coastal fish and shellfish populations due to the rapid loss of coastal marsh."

The first two items are directly relevant for the Keys. The third is of primary relevance for the environmentally degraded Everglades, which causes pollution across the Florida Bay to the Keys. The fourth point focuses on coastal marshes which are prevalent in mainland Florida. Other wetlands, however, are prevalent in the Keys (mangroves and adjacent seagrass beds).

The following specific points relating to Florida supplement the above picture (page references from Karl et al. 2009):

- Large urban population growth rates are occurring in South Florida, Atlanta, California, Phoenix, Las Vegas, Denver, Dallas, and Houston (p 54)
- The four most populous States, California, Texas, Florida and New York, grew from 90 million to 100 million between 2000 and 2009, 39% of the total US population growth in that period, with the strongest growth rate in Texas followed by Florida (update of Karl et. al. 2009). These States also share significant vulnerability to coastal storms, severe

drought, sea-level rise, air pollution, and urban heat island effects. Continued population growth is projected for southern coastal areas. “Overlaying projections of future climate change and its impact on expected change in US population and development patterns reveals a critical insight: more Americans will be living in the areas that are most vulnerable to the effects of climate change.” (p 100)

- Over the past century, the Southeast “sunbelt” has attracted people, industry and investment. The population of Florida more than doubled during the past three decades. Future population growth and the quality of life for existing residents are likely to be affected by the many challenges associated with climate change, such as reduced insurance availability, increased insurance cost, and increased water scarcity, sea-level rise, extreme weather events, and heat stress. Some of these problems, such as increasing heat and declining air quality, will be especially acute in cities (p 116).
- Future water constraints on electricity production in thermal power plants are projected for Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, California, Oregon and Washington State by 2025 (p 56).
- Water stress causes disputes across the country, with Georgia, Alabama, and Florida arguing over water for drinking, recreation, farming, environmental purposes, and hydropower (p 48).
- Florida’s energy infrastructure is particularly vulnerable to sea-level rise and storm impacts. Most petroleum products consumed in Florida are delivered by barge to three ports. South Florida (12 counties) is served by Port Everglades, Fort Lauderdale (p 59).
- Florida and Louisiana are suffering increasing salinity of surface water resources (p 43).
- “Average autumn precipitation has increased by 30% in the region since 1901. The fall in precipitation in South Florida contrasts strongly with the regional average.” But summer drought has increased since 1970 in the whole region. South Florida has experienced a nearly 10% drop in spring, summer and fall precipitation. Spring and summer rainfall is projected to decline in South Florida during this century (pp 111-112).
- The destructive potential of Atlantic hurricanes has increased since 1970, correlated with an increase in sea surface temperatures (p 112).
- Three different types of adaptation to sea-level rise are listed on p 116: (1) move buildings and infrastructure farther inland (not good advice for the Keys), (2) accommodate rising water through changes in building design and construction, such as stilts, and (3) build levees and river flood control structures. Construction is costly, however, and building levees can actually increase future risks if increased perceived safety leads to further development. Levees built for category 3 hurricanes are useless when a category 5 hits.

3.3 IMPLICATIONS FOR THE FLORIDA KEYS

It is useful to think of the Keys as a collection of mutually dependent ecosystems – a “higher-order” or “super” ecosystem. It neatly focuses attention on the total entity that is at risk as well as the parts. The following definition owes much to personal communication with Chris

Bergh who elaborated on an original draft definition by highlighting the uneasy interactions of the component ecosystems with the socioeconomic realities:

The Keys, in an important sense, are an ecosystem in itself, with its collection of islands complete with key deer and other threatened species, pine forests, hammocks, mangrove and seagrass communities, and the coral reefs. This uniquely interdependent collection of natural communities and species exists in an already uneasy balance with the Keys' residents and visitors. Both the social and natural components of the system are under threat, aggravated in a "business-as-usual" future.

Much of what Karl et al. (2009) write about the Southeast applies also to the Florida Keys, and largely confirms the findings from our scenario-planning workshops in June 2008 (see Appendices 1 and 2). Adapted to the Keys, and assuming that the projections for the Southeast reflect "business-as-usual" ("BAU") rather than prompt transition to a greener society, the following list relates primarily to the impact of natural forces exacerbated by human-induced climate change:

- The background is that air and sea temperatures have been rising in the United States and will keep doing so at an increasing rate, at least in a "BAU" scenario. Taken this as read, the other items following below are listed in approximate order of importance, given that the items depend on and feed upon each other. This is reflected in the last item in the list, which refers to possible domino effects in the higher-order ecosystem defined above.

- The threat of sea-level rise profoundly affects the Florida Keys. The average elevation of the larger islands range from four to seven feet or 1.2 to 2.1 meters (Monroe County 2005). An analysis by The Nature Conservancy (Bergh 2009, p 25) shows that even according to the most optimistic IPCC scenario (an average sea-level rise of 18 cm by the end of the century), 38% of the total Keys area will risk inundation. This increases to 75% according to the most pessimistic IPCC scenario (average sea-level rise 59 cm).

  Using an assumption of a 140 cm rise in the average sea level which looked radical when first published (Rahmstorf 2007), the estimated loss increases to 92% (95% for Big Pine Key which Bergh explored in most detail). Worst-case scenarios have moved closer to the center of the probability distribution over the past few years (Hoegh-Guldberg 2010a). Stefan Rahmstorf is an acclaimed climate scientist at the Potsdam Institute of Climate Impact Research, and his assumptions are now deemed to be within the range of what could be expected.

  Bergh (2009) notes that the projections do not incorporate local subsidence (geological "sinking" of the land), which adds an estimated 10 cm over the century. On the other hand, some parcels included in the 2008 "starting acreage" may have been already fully or partly submerged. The qualifications are noted but do not alter the basic conclusions.

- Hurricanes have become more violent and more frequent. This trend is projected to continue, affecting the Keys as much as or more than any other part of the United States.

- Other extreme weather events (droughts and heat waves) will also increase in intensity.

- The coral reefs are the signature ecosystem of the Florida Keys. They are increasingly affected by coastal pollution, bleaching events, ocean acidification, and damage caused by tourists, fishing vessels, and cruise ships.
- Domino effects are likely to exacerbate conditions in this uniquely interdependent collection of ecosystems, especially in a “business-as-usual” future. The key deer is an example. Being confined largely to Big Pine and No Name Keys where the maximum natural elevation is 2.4 m above the median sea level (Bergh 2009, p 4), the species is clearly threatened. “Median sea-level rise coupled with storm surges would inundate most of the available habitat either permanently or episodically, further threatening this endangered species.” (Janetos et al. 2008, pp 162-163)

In summary, the above items, caused by climate change aggravated by human activities, pinpoint the impact of climate change on the Florida Keys:

1. Accelerated sea-level rise
2. More powerful and numerous hurricanes and other extreme weather events
3. More hot weather and droughts
4. Further deterioration of coral reefs due to bleaching, pollution, disease, and ocean acidification
5. Deterioration of other ecosystems including mangroves and seagrasses
6. An increasing risk that the various components will unite to form domino effects on the total Florida Keys “super” ecosystem.

This leaves out external factors that will interact with those already listed:

- Population pressures from the north. The Keys are in a unique situation of having a permanent population of less than 75,000 (and shrinking), close to its carrying capacity and situated next-door to the largest population center in Florida (5.5 million) – with all that this implies in terms of competition for resources such as water and energy supplies, and having to cope with infrastructure which inevitably intrudes on local arrangements, and increased intrastate tourism and other population movements.
- Environmental pressures from the Everglades National Park, which has itself been badly degraded by the population growth in South Florida and which is causing major pollution of Florida Bay and the Florida Keys.
- Buildings and infrastructure in the Keys will become increasingly unsuitable as the climate warms and associated events start to bite. This is already happening to petroleum supplies (through Port Everglades) and water supply (salinity entering aquifers).
- Direct threats to main income sources for the Keys, primarily tourism but also fisheries.

The policy implications in Chapter 8 follow logically from the above premises, coupled with insights from a number of reports including one in which another area containing coral reefs has been adapted to the Florida Keys.

4 Florida Keys overview

Following a description of the Keys in Section 4.1, the second section on issues was derived from scenario-planning workshops which the author conducted in five locations along the Keys in June 2008. The workshop proceedings, recorded verbatim, revealed a number of key issues shown in Section 4.2. The subjective descriptions based on the workshops are complemented with supportive factual information when required. Refer Appendix 1 for the identified key issues and Appendix 2 for a distillation of the original workshop transcripts.

Section 4.3 deals with the integrated coastal management of the Florida Keys National Marine Sanctuary, and Section 4.4 highlights the importance of local and worldwide non-government and voluntary organizations in the area.

4.1 Monroe County

4.1.1 General

The most detailed description is in the Monroe County 2010 Comprehensive Plan (accessible through http://www.monroecounty-fl.gov). It was prepared in 1991 in compliance with the requirements of the State of Florida to develop such a plan. For our purposes, a summary description in Chapter 2 of the Local Mitigation Strategy Plan (Monroe County 2005) provides a convenient framework.

Monroe County is the southernmost county in the United States. The total area is about 1,875 square miles (4,850 km^2), but large portions are submerged lands associated with parks and preserves that are under the jurisdiction of the federal and state governments. The total land area is approximately 885 square miles (2,300 km^2), mostly on the mainland within the virtually uninhabited Everglades National Park and Big Cypress National Preserve.

The Florida Keys themselves, which are our main concern, consist of about 102 square miles (264 km^2). They form an elongated chain of about 1,700 low-lying islands more than 220 miles (>350 km) in length from the southeastern tip of the Florida peninsula to the Dry Tortugas. Excluding the latter, Mile Marker 0 is at Jackson Square, Key West, and MM 107 at the northern boundary of Key Largo (that is, 172 km from MM 0). The highway known locally as the Overseas Highway connects all locations between the two (it is actually the southernmost stretch of US 1 which runs along the entire Atlantic coast from Maine south).

The Upper Keys cover the islands from Key Largo to Lower Matecumbe Key (Islamorada). The northern boundary of the Middle Keys is Craig Island, across the causeway and bridge from Lower Matecumbe Key. The southern boundary is the Seven Mile Bridge south of Marathon. The Lower Keys, with the largest number of islands, extend from Little Duck Key at the southern end of the Seven Mile Bridge, to Key West. Islands on the road to Key West include Big Pine, Summerland, Cudjoe and Sugarloaf Keys. Big Pine Key is the second-largest island in the Florida Keys (25.3 km^2).

The Keys include incorporated cities (Islamorada in the Upper Keys, Marathon and the smaller Key Colony Beach and Layton in the Middle Keys, and Key West in the Lower Keys), and unincorporated areas including sizeable population centers in the Upper Keys (Key Largo, Tavernier) and the Lower Keys (Big Pine Key).

The Keys lie between the Gulf of Mexico and the Atlantic Ocean – dangling from the mainland like "hurricane bait" according to the Local Mitigation Strategy Plan (Monroe County 2005, p 2-1). The islands at the extreme ends of the chain are relatively big: Key West (13.6 km^2) with a natural deep water harbor and the largest population of some 25,000, and 48 km-long Key Largo in the north the largest at 31.6 km^2. The Keys are rocky islands and sandy beaches are not common, though some exist.

Just miles offshore on the Atlantic side of the Keys is the only living coral reef in the continental United States – the third-largest barrier reef ecosystem in the world after the Great Barrier Reef in Australia and the Yucatan Peninsula/Belize reef system.

No point in the Keys is more than four miles from water, and the vast majority much closer. The highest point, Solares Hill in Key West, is 16 feet (5 m) above mean sea level. The highest elevations of the larger islands are four to seven feet (1 to 2 m).

4.1.2 LAND USE AND GROWTH TRENDS

The total permanent resident population of the Keys increased slightly from 78,024 in 1990 to 79,589 in 2000 according to the ten-year US Census, but this conceals that the population increased to over 82,000 in 1993 and has fallen since. The latest estimate (2009) shows a fall to 73,165, continuous from year to year with the largest falls happening in 2004, 2005, and 2006 (long-term statistics and further discussion in Chapter 6). This contrasts with estimates on the Monroe County website showing population growth, which may be due to an increase in number of people owning property but not living there permanently, an issue mentioned in the 2008 scenario-planning workshops (see Section 4.2.7).

Growth trends in Monroe County are regulated through the number of residential permits issued – the so-called ROGO system (Rate of Growth Ordinance). "The majority of the new residential permits issued are for permanent residential use although some permanent dwellings are used by seasonal residents." (Monroe County 2005, p 2-3)

Incorporated cities administer their own ROGO allocations within the overall boundaries available for the County. Nonresidential permits are linked to the residential allocations; In effect, the area of new commercial development that may be permitted is limited to 239 square feet for each new residential permit issued (p 2-5).

4.1.3 ECONOMIC CHARACTERISTICS

With very little industrial and agricultural activity in the Keys, the predominant form of nonresidential development is commercial. The two primary types of commercial development are retail trade and services (which include tourism-related development such as marinas and restaurants).

In 1999, there were approximately 175 hotels and motels with a total of over 7,200 rooms, numerous rental homes, 109 mobile home/recreational vehicle parks, 6,100 individual mobile home parcels, and over 2,800 campsites. Services, dominated by hospitality (food and lodging), is the largest segment of the private sector, followed by retail trade. These industries accounted for nearly 52% of total employment, and 67% of private sector employment. For a more comprehensive and updated statistical picture, see Chapter 6 (Table 6.6 in particular).

Commercial fishing according to the County represents 7% of total employment and 9% of private sector employment. A combination of economic and natural resources factors have led to a decline in the number of commercial fishing vessels and a long-term downward trend in the total weight of the harvest. This figure cannot be comprehensively updated, as “forestry, fishing and related activities” was a confidential category in the official NAICS statistics classification, except for 2005, when the total was 1,245. Even assuming this was all fisheries, it represented only 2.2% of total employment and 2.6% of private employment – much less than reported in the Monroe County documents cited.

Two other private sector categories together accounted for about 15% of total employment: construction and finance/insurance/real estate. Public sector employment accounted for just over 20% of total employment, including the federal government and military, state and local government agencies, and utilities. Again, refer Table 6.6 for updated official statistics.

4.1.4 TRANSPORTATION

The transportation network in the Florida Keys is unique in that a single road forms its backbone and the sole link to the Florida mainland. US 1 is a lifeline for the Keys, functioning as both highway and “Main Street”. Each day it brings food, materials, and tourists from the mainland, driving the local economy. (Monroe County 2005, p 2.6)

Monroe County is also served by two airports: Key West International and Marathon, the former serving the major commercial airlines. Finally, cruise ships enter Key West as a major activity for that town. Airline and cruise ship statistics are shown in Chapter 6.

4.1.5 ENVIRONMENTAL RESOURCES

The Florida Keys contain unique habitats, with many rare and endangered plant and animal species. In 1980 the State of Florida legislated to designate the Keys portion of unincorporated Monroe County and the incorporated municipalities as *Areas of Critical State Concern*. The purpose of the program is to protect the unique environment, vegetation, and natural resources of the designated area by regulating land development and other activities regarded as detrimental to the environment.

The legislature also enacted *Principles for Guiding Development*, providing for State oversight of development and changes to land use regulations, a function carried out by the Department of Community Affairs. The Department established Field Offices in Monroe County to assist in review of development permits and related issues for compliance with the *Principles*.

The following environmentally sensitive *Special Management Areas*, submitted by the Marathon office of the Florida Department of Environmental Protection, illustrate the uniqueness, geographical range and variety of the environmental resources of the Florida Keys:

- The *Florida Keys National Marine Sanctuary* is evidently in a category of its own, but the list of marine sanctuaries also includes John Pennekamp Coral Reef State Park (Key Largo) and the adjacent Key Largo National Marine Sanctuary, and Looe Key National Marine Sanctuary (five nautical miles offshore of Big Pine Key). The two national sanctuaries were established in 1975 and 1981, respectively, and were formally incorporated into the FKNMS in 1990 though they also retain a separate identity.

- *Land-based parks* nominated for their natural value comprise the Key Deer National Wildlife Refuge (Big Pine Key) and Great White Heron National Wildlife Refuge (unpopulated islands north of Lower Keys), Windley Key Fossil Reef State Geological Site (Upper Keys, including a fine tropical hardwood hammock forest), Lignum Vitae Key State Botanical Site (off Islamorada, featuring tropical hardwood hammocks), Long Key State Park (Layton, Middle Keys), and Curry Hammocks State Park (Grassy Key near Marathon, Middle Keys).
- *Four historically based parks* are Bahia Honda State Park (Lower Keys, near historic Flagler railway bridge, also including nature park and sandy beach), Fort Zachary Taylor State Historic Site (Key West), Indian Key State Historic Site (off Islamorada), and San Pedro Underwater Archaeological Preserve (near Indian Key).

4.1.6 Historic resources

Monroe County has about 330 locally-designated sites identified under Article 8 of the Monroe County Code as Archaeological, Historical, and/or Cultural Landmarks (available on the County's webpage). Key West's Historic Architect Review Commission has locally designated about 2,300 sites, dramatically indicating the uniqueness of that city, which adds an important dimension to the Florida Keys as a tourist destination as any visitor can see.

4.1.7 Green teams

It is important to add that Monroe County takes initiatives that don't find their way quickly into official publications like the Comprehensive Plan. For example, the Green Initiative Task Force (GITF) was created on June 18, 2008 by the Monroe County Board of County Commissioners (BOCC). The scope of the task force is to provide recommendations to the BOCC of environmentally sound practices and techniques to protect the environment as well as climate change recommendations.

The task force has to prove itself quickly, however. BOCC has resolved that it has a sunset date of October 1, 2010. (Late addition: This actually happened, but the Board of County Commissioners may reestablish the GITF, or something like it, in 2011. Chris Bergh, personal communication, October 24, 2010.)

4.2 Eight issues

Appendices 1 and 2 deal with issues identified from five scenario-planning workshops in June 2008. The 60 participants included senior local politicians, business people, major non-government organizations, scientists, and other opinion leaders. Ten members of the Sanctuary Advisory Council took part. Eight issues were extracted from the transcripts: four that are hard to control locally, and four potentially more manageable ones (Appendix 1). Appendix 2 distills the 70,000 words of the transcripts down to 12,000, sorted by the eight issues and the workshop location (while respecting the anonymity of the participants).

The workshop proceedings are subjective, a canvas of views generated in five two-hour meetings with as little interference as possible from the writer who acted as the workshop moderator. The purpose was to find the real issues through a free-flowing discussion, which could only be done locally and with minimal guidance to the group other than setting the stage and outlining the objectives.

Each issue is described below, based on the workshops but complemented by scientific and other evidence on particular matters, such as the impact of climate change itself, planning for water supply, carrying capacity, and so on. It is hoped that this combination of informed local opinion and factual evidence reinforces both.

The first four issues are those hardest to control locally.

4.2.1 CLIMATE CHANGE – THE PRIMARY ISSUE

Every scenario-planning workshop saw climate change as the underlying force and prime issue, centered on but not confined to the reef and marine environment.

- Increased sea temperatures affect coral health, causing bleaching accompanied by a range of other marine diseases. Coral cover is lost, especially on shallow reefs. It was noted that bleaching occurred 12 years earlier in the Greater Caribbean than in other parts of the world. This implies that the impact has had more time to establish itself here as the sea takes a decade or so to absorb higher air temperatures.
- On land, there is loss of endemic species of plants, wildlife and invertebrates, and invasive species take over ecological niches.
- The sea is rising much faster than projected. This has many effects, including salt water intrusion into the Biscayne Aquifer which provides fresh water for the Keys (see next section), difficulties with low-grade sewer systems dealing with sea-level rise, and a continuing need for better stormwater and wastewater facilities in Miami-Dade, Broward and Palm Beach Counties. Conditions are deteriorating for birds and fish at low tide. Ultimately, the sea-level rise could flood most of the Keys.
- Ocean acidification is exacerbating the impact of warming along the Keys. (We note that the issue has gained much impetus since 2008, when it came up in only the Islamorada workshop. See further below.)
- The jury is out on whether there will be more hurricanes, and/or more intense ones (the scientific evidence (Karl et al. 2009) shows an increase in Atlantic hurricane intensity).
- From an economic point of view, climate change will pose an increased threat to fisheries, and to real estate values. Meanwhile, climate change skeptics and deniers are still causing delays in dealing with the problems.

These subjective statements have abundant scientific support. The Nature Conservancy's Florida Keys office in April 2008 organized a two-day reef resilience conference in Key Largo with the theme "Coping with climate change". One example was a wide-ranging review by Keller and Precht (2008), adopting a spatial perspective on variation among coral reef systems in the Greater Caribbean and the Great Barrier Reef, a temporal perspective on the Florida Reef Tract over 125,000 years of changing climates and sea levels, and outlining the management implications: how to reduce the human impact, and anticipate further changes.

Keller and Precht were especially concerned with the "shifting baseline syndrome" occurring over the past 30-40 years:

- Shifting baseline 1: Die-off of *Acropora palmata and A. cervicornis* (Elkhorn and Staghorn coral) in the late 1970s to 1980s
- Shifting baseline 2: Mass mortality of the herbivorous *Diadema* sea urchin between January 1983 and January 1984
- Shifting baseline 3: From the first coral bleaching event in the Lower Keys in 1983 to mass global bleaching events in 1997-98
- Shifting baseline 4: Proliferation of coral diseases in the 1980s and 1990s.

Ocean acidification within a few years has emerged as a threat to coral reefs on a par with global warming itself (Hoegh-Guldberg et al. 2007). Indeed as noted in Chapter 3 it is now being dubbed "the evil twin of global warming" (as quoted by Pelejero et al. 2010), referring not just to coral reefs but the oceans generally. The "twins" are of course both the progeny of greenhouse gas emissions.

The Florida Keys Sanctuary Advisory Council in August 2009 passed a resolution recognizing the threat from ocean acidification, following a presentation by the Southeast Regional Director of the National Marine Sanctuary Program (Causey 2009). The threat of rising sea levels caused by climate change has been demonstrated dramatically by Bergh (2009), using a range of projections to show the potential loss of land area and values as sea levels rise. These and other scientific contributions are taken into account in the scenarios in Chapter 7.

4.2.2 WATER SUPPLY

The workshops noted (Appendices 1 and 2):

- The Biscayne Aquifer is increasingly threatened by seawater intrusion, which will be exacerbated as the sea level rises. There are cumulative effects of drought in South Florida, and fresh water is becoming the limiting factor for development. One participant referred to water as "the new oil" in terms of its actual and potential scarcity.
- Alternative sources are expensive: current treatment of wastewater in Miami-Dade County leaves it mainly non-potable, but reverse osmosis technology (which removes salt by forcing brackish or salt water through fiber membranes) may bring the quality up to potable.
- Local remedial action is important: rainwater cisterns are being reintroduced, and residents are converting septic tanks (being replaced by sewerage systems) to water storage systems. Some homes provide all their water needs, using solar energy.

The Florida Keys Aqueduct Authority (FKAA) channels water from a well field near Florida City in Miami-Dade County. Its history goes back to 1937, when its predecessor, the Florida Keys Aqueduct Commission, was created to obtain an adequate sanitary water supply for the Keys. In 1939, the US Naval Air Station near Key West was re-activated and a military build-up started. This required a large additional supply of water, which led to an agreement between the Department of the Navy and the Commission. The Navy acquired 360 acres near Florida City in Miami-Dade County, drilled wells and constructed a filtration plant. The pipeline had a capacity to carry 3 million gallons per day (MGD), of which the naval base required two-thirds, leaving one-third for the Commission.

The capacity has been progressively increased, especially since FKAA took over from the Navy in 1976. The Authority currently operates three water treatment facilities to meet its water supply needs. Groundwater from the main freshwater 130-mile Biscayne Aquifer (located 30 to 100 feet below the surface) and the deep brackish-water Floridian Aquifer 1,700 feet down is lime-softened at the water treatment plant near Florida City. Seawater from wells is desalted using reverse osmosis membrane technology at two emergency water supply plants at Stock Island and Marathon (FKAA 2006a,b). They are capable of supplying 3 MGD, but costs are high so these plants are used in emergencies only.

The Biscayne Aquifer is under increasing strain because it also serves as the principal source of fresh drinking water supply for all of Miami-Dade, Broward and Palm Beach Counties. The rapid population growth and rising water demand in Southeast Florida has forced the South Florida Water Management District to put strict restrictions on the quantity of water that users can continue to withdraw from the Biscayne Aquifer, especially during the dry season when the aquifer receives less recharge from rainfall. FKAA's well field is particularly vulnerable to withdrawal restrictions because of its close proximity to the Everglades National Park to the west, and to the saltwater intrusion line to the south and east.

The withdrawal restrictions mean that an alternative water supply must be secured in order to augment the current water treatment capacity of the system, as is happening with the construction of aquifer storage and recovery (ASR) wells deep enough to reach the Floridian Aquifer. These moves were endorsed by the South Florida Water Management District and the Department of Environmental Protection as a viable alternative source of water supply.

In support of this initiative, FKAA filed the appropriate documents and received all required regulatory permits needed to construct an ASR well with an estimated depth of 1,350 ft. The volume of water yielded during each "recovered" cycle is treated and blended with water extracted from the Biscayne Aquifer, thus increasing the output of the water treatment system without exceeding the withdrawal allocation permit of the Biscayne Aquifer.

In January 2010, a reverse osmosis plant was opened at the main FKAA treatment plant at Florida City to supplement the 17 MGD which is the limit that FKAA can draw from the Biscayne Aquifer. The new plant draws on the brackish waters of the Floridian Aquifer. It is capable of adding 6 MGD to the maximum 17 MGD available through the Biscayne Aquifer. Using reverse osmosis to remove salt from brackish water is considerably less expensive than to remove it from sea water (Wadlow 2010).

FKAA faces significant challenges in meeting the projected water demand for the next twenty years. Functional population projections (residents plus the population equivalent of tourists) used to develop water consumption needs to 2025 indicate that the daily production rate must be increased from 23.79 MGD to 29.11 MGD (FKAA 2006b). This increase in production capacity will also require significant improvements to the water treatment system.

These initiatives have important links to the recovery strategy for the waters of the Everglades National Park, with which the water supply program is intimately connected. The once vibrant Florida Everglades is now a dying ecosystem (FKAA 2006a), with a vast reduction in its natural water flow, combined with loss of 50% of its wetlands and other factors related to South Florida's rapid growth. The US Army Corps of Engineers in partnership with the South Florida Water Management District have developed a plan to save the Everglades. The Comprehensive Everglades Restoration Plan describes a series of projects to take place over more than 30 years to restore the ecosystem, largely focusing on improving water deliveries.

4.2.3 Carrying capacity

It was noted in the scenario-planning workshops that the carrying capacity study (URS Corporation 2002) is based on an endangered species model including hammocks connectivity and endangered species mainly in the Lower Keys (Key deer, Lower Keys marsh rats, and others). Relevant other documentation includes the 20-year Monroe County 2010 Comprehensive Plan, adopted in 1993. To curb excessive growth occurring in the 1980s, the Rate of Growth Ordinance (ROGO) was introduced in 1992 to limit the number of building permits, and restrict building heights. The aim was to bring the population in line with the mandatory time for hurricane evacuation.

Together with its non-residential counterpart, NROGO, ROGO controls growth throughout Monroe County, but while it was effective in this, causing new building permits to fall to about one-fifth of the level in the 1980s, it became too complex. A Tier System introduced in 2006 greatly simplified the ROGO process and introduced a method for directing growth to acceptable areas and allowing conservation in areas of environmental sensitivity on Big Pine Key and No Name Key, the main habitats of the endangered Key deer (*Odocoileus virginianus clavium*), remnant descendants of an original colony of white-tailed deer (*O. virginianus*). These systems are explained in various Monroe County publications, including a “layman’s guide” (2006).

Population issues noted in the workshops (directly or indirectly associated with carrying capacity) indicated a variety of concerns for the future, many of which are borne out by recent statistics and other research including analysis of the NOAA visitor survey in 2007-08:

- Just too many people (locals and visitors) for too small an area
- Losing our workers, and volunteers
- Few young people return to work in the Keys
- Population projected to double in size in Florida by 2060 (Zwick and Carr 2006)
- Whether to discriminate between types of residents and visitors to attract to the Keys
- Litigation costs are high if trying to prevent people from coming here
- Keys may become almost entirely populated by the wealthy
- Transient community – people living here part-time only
- Special issues in Key West: Dilution of unique heritage through unbridled development; drastic community change could happen; newcomers’ lack of understanding of heritage.

The Florida Keys carrying capacity study (URS Corporation 2002) used a "carrying capacity analytic model" (CCAM) consisting of a number of interrelated modules:

- *Socioeconomic impacts*: Permanent, seasonal (staying 30-180 days a year), and transitional (less than 30 days) population adding to the total "functional" population; number of dwellings; tourism numbers and associated infrastructure and earnings.
- *Fiscal impact*: additional government capital expenditure on improving the US 1 highway, wastewater, stormwater, land acquisition, and restoration.
- *Infrastructure impacts*: potable water, traffic, hurricane evacuation.
- *Terrestrial ecosystems and species*: Habitat loss and fragmentation (loss of half the habitats existing prior to development; fragmented into smaller patches, averaging five acres now compared with 100 acres prior to development; number of upland patches up from 160 in 1800 to 200 in 1945 to 500 in 1995. Species richness: Key deer tripled in numbers since 1970s in their small area (mainly Big Pine and No Name Keys).
- *Marine ecosystems and species*: water quality, water conservation, pathogens in the marine environment, effects of nutrients on benthic communities, direct human impacts on marine resources (propeller scarring, snorkeling and diving impacts on coral reefs, recreational fishing).

Carrying capacity was defined as the maximum level of development that could be supported without damage to the natural and human resources of the area. Some of the main conclusions were (Chapter 5):

- *Terrestrial ecosystems and species*: Land development has displaced 50% of upland habitats and lost areas of saltwater headlands. More than 90% of remaining uplands are distributed in patches of 10 acres or less. Loss of key ecological functions are estimated to happen below 13 acres. Terrestrial habitats show concentrations of tropical, Caribbean and temperate species unique in the US: over 100 species occur only in the Florida Keys.
- *Human infrastructure*: Six future scenarios all call for small growth in population and number of dwellings (less than 10%, mostly less than 5%) over the 20 years following the study. However, even small growth may place stringent demands on some infrastructure capacities: expanding the capacity of the US 1 highway; water withdrawals growing faster than population requiring alternative water supplies including more reverse osmosis desalination plants.
- *Socioeconomic impact*: The study suggests that the small increases in the permanent population "are unlikely to affect the overall socioeconomic structure of the Florida Keys" (p 120). (*This was **not** the view of the workshop participants summarized above under population issues – a view which seems closer to the truth, subjective or not.*) Also, according to the carrying capacity report, an increase in visitor numbers assumed in one of the scenarios would impose additional demands on tourist-related land uses, water supply, and recreational opportunities.
- *Fiscal impact*: In contrast to a generally modest impact due to growth, "the six future scenarios would result in a disproportionate increase in government expenditures with

respect to the projected increase in population. Per capita annual expenditures are likely to increase in all the scenarios, creating immediate pressure for government to increase revenue. Tax increases on both the local population and visitors would likely occur." (p 121)

- *Marine ecosystems and species*: "The existing data are insufficient to establish quantitative, predictive relationships between land use or development and the marine environment. However, there is plenty of evidence of human effects on the marine ecosystems and species in the Florida Keys." (p 121) The evidence includes seagrass scars, boat groundings, beach closures, coral collisions, and poor water quality in the canals.

Suggested guidelines include preventing encroachments into native habitats, already badly damaged; combining and intensifying the many existing programs (land acquisitions, wastewater and stormwater plans, the ongoing research in the Sanctuary, and restoration work); focusing on redevelopment if further development is to occur; and increasing efforts to manage habitats to preserve and improve the ecological nature of the remaining terrestrial ecosystems.

The carrying capacity study was criticized in a National Research Council report (NRC 2002) on a number of grounds:

- The socioeconomic impact of tourists was not estimated separately, which precluded modeling of their activities, such as boating, fishing, and diving. The socioeconomic module therefore accounted too simplistically for tourism, as well as having no useful indicators of quality of life.
- The human infrastructure module only dealt with traffic and hurricane evacuation times.
- The marine module did not have good data and would require almost complete revision (the terrestrial module was more successful in securing data).

In conclusion: "Endeavors such as CCAM tend to obscure significant environmental uncertainty and project an unrealistic understanding of complex environmental issues. The CCAM has important information particularly when modules are based on good and reliable scientific data. But in the end decisions to be made will be social not scientific." (p 4)

The carrying capacity study, nonetheless, has been influential in setting boundaries for the growth potential of the Florida Keys, limited by resource constraints. In fact, the population has continued to fall, rather than showing small increases, though this may be at least partly due to the influence of the strongly increasing non-resident ownership of condominiums and time-share premises.

The carrying capacity study has been in existence for almost a decade, and prospects must now be seen also in the light of a more severe climate change outlook. This and the apparent failure of the carrying capacity study to acknowledge that the demographic and socioeconomic structure in the Florida Keys is changing means that a reappraisal is required. This project cannot provide this in any detail, but it can at least indicate in a general way how structural demographic and socioeconomic change may affect the local scenario assumptions in Chapter 7.

4.2.4 OTHER EXTERNAL INFLUENCES

Three main groups of external issues arose from the workshops, mainly as threats rather than opportunities. The first group is associated with the rest of the United States and resulting pollution of the Gulf of Mexico, the second more specifically with the rest of Florida including pollution of Florida Bay and the Keys from a degraded Everglades ecosystem, and the third with Cuba:

- Red tide from Mississippi, runoff; flooding Ohio and Mississippi Rivers; algal blooms in Gulf. (The workshops might also have commented on President Obama's decision to allow oil and gas exploration in the Mexican Gulf and elsewhere along the US coast, and the Deepwater Horizon oil spill off Louisiana only a month after his announcement – except it only happened in 2010.)
- Influences from the rest of Florida include stormwater from the Everglades influencing water quality in Florida Bay and elsewhere along the Keys; pollution from a Florida sugar cane industry expanded for biodiesel; pressures from densely populated counties to the north including new development projects in Miami-Dade County; lack of control over ocean outfalls to the north. One specific problem was that even if US 1 was upgraded in the Florida Keys, effective hurricane evacuation would still depend on the roads north being able to handle the impact of a strongly growing population around Miami.
- The main potential threat from Cuba was commencement of offshore drilling, with the main threat to the Dry Tortugas. Mixed opportunities and threats were associated with the opening up of Cuba for tourism: competition from Cuban dive spots, potential opportunities to cooperate on ferry and air transport, and sharing destinations with Cuba.

Some of the issues above are dealt with in the scientific literature. For now they flag a number of concerns that have to be managed.

The second set of issues identified from the workshops falls into the "more manageable" category. They also provide an opportunity to focus on the most important features for future planning: the resilience of coral reefs, their vulnerabilities, and the critical importance of marine sanctuaries, all of which will have a strong impact on the local scenario building in Chapter 7.

4.2.5 REEF HEALTH, SUSTAINABILITY, AND FISHERIES

The scenario-planning workshops identified three main factors, and the overlap with the first issue, climate change, is clear from the outset. But this looks at what is locally possible. The descriptions in the three main groups provide a generalized picture of local opinion leaders' concerns:

The major factor is warming, with the following positive comments on how to adapt:

- Local action is possible towards environmental sustainability, the main long-term goal. There is important ongoing work on coral reef resilience (the dominant theme further discussed below), on continued sanctuary development, and on efforts to restore the major reef-building Elkhorn and Staghorn corals (*Acropora palmata* and *A. cervicornis*).

- Martin Moe supported by MOTE Marine Laboratory has worked to restore the herbivorous long-spined sea urchin (*Diadema antillarum*) as a lost link in the chain keeping the reef ecosystem healthy. Before it succumbed to disease in 1983, this urchin maintained the ecological balance between coral and macroalgal growth on Atlantic reefs. Three years of work to develop a process for mass culture of the urchin finally proved successful in 2009, and the task is now to return it in ecologically functional numbers:

  "If we could produce large numbers of healthy juvenile *Diadema* in hatcheries in a variety of sizes and ages, with appropriate genetic background and high health, and learn to stock them responsibly and effectively, it would be an exceptional tool for research and development projects for ecological restoration on selected coral reef areas. In fact, it may be the only effective biological tool available for ecological restoration of Atlantic coral reefs." (Moe 2009).

  The Coral Reef Evaluation and Monitoring Project (CREMP) records the number of stations in its coral reef watch that observe *Diadema antillarum.* While still a small fraction of the total 113 CREMP stations, the number observing the urchin increased from four in 1996 to 13 in 2005 (but then declined to nine in 2006) (Callanan et al. 2007). This is not an explosive recovery in the natural environment, but at least there appears to have been some progress.

The following points are listed for additional perspective:

- Some senior members of the Florida Keys community commented on the great deterioration of the reefs that has occurred since the 1950s-1960s ("shifting baselines"). This was already a main theme in Gilbert Voss's book on Florida's coral reefs (1988).
- These reefs are more vulnerable than the Great Barrier Reef due to their proximity to the coast.
- Bleaching events here preceded similar events elsewhere by at least 10 years.
- Reef health is vital to reef use, including fisheries.
- "We all need to get on the bandwagon to promote reef health", like local organizations GLEE (Green Living and Energy Education) and SFFFK (Sanctuary Friends Foundation of the Florida Keys).

Water quality:

- Restoring the Everglades is essential for fisheries and drinking water supply (increasingly exposed to saltwater intrusion).
- The Keys act as a turbidity barrier. Tumors in turtles, lobsters, shrimp, and fish are associated with the connectivity of systems: the water quality problems are broader than they used to be. The theory is that outflow of organic matter (hormones, pharmaceuticals), mainly from cruise ships, causes the problem (aided by outflows from septic tanks along the Keys). The greater abundance of coral in the Upper Keys compared with Marathon may be due to fewer openings from the bay side to the ocean side – so the islands actually act as a turbidity barrier (Appendix 2).

Fisheries:

- Monroe County is a major commercial fisheries area (especially for groupers, snappers and other reef fish, and spiny lobsters, as shown in Chapter 5).
- The overriding issue is how to support fisheries but to limit the damage from fisheries to sensitive ecosystems and reefs: prop-dredging, anchor damage, lines trapped around coral – "reef death from a thousand cuts", as one participant put it.
- *Commercial versus recreational fishers*: issues with division of fish stock; access problems for commercial fishers due to rich recreational fishers; in contrast to recreational fishing, commercial fisheries are strictly regulated; declining fish size due to overfishing; the long-term increase in fishing pressure will continue after the current recession; need to educate some commercial fishers how to conduct good businesses.
- Associated issues: Excessive use of the Global Positioning System (GPS) to identify catches. One important benefit of zoning is increased yield in unprotected areas.

Resilience and reef health: The subjective workshop observations are again well supported. The Nature Conservancy in April 2008 organized a major reef resilience conference in Key Largo, *Coping with Climate Change*, sponsored by the Florida Reef Resilience Program (FRRP). As well as providing a forum for managers to exchange experiences at roundtables and other events (see FRRP 2008), the three-day conference was addressed by a number of scientists, sanctuary managers and others. All presentations can be found at http://frrp.org.

FRRP is a public and private partnership that brings scientists, reef managers and resource user groups together to develop strategies to improve the health of Florida's reefs and enhance the economic sustainability of reef-dependent commercial enterprises. Figure 4.1 provides a simple illustration of the concept, from one of several versions presented at the resilience conference.

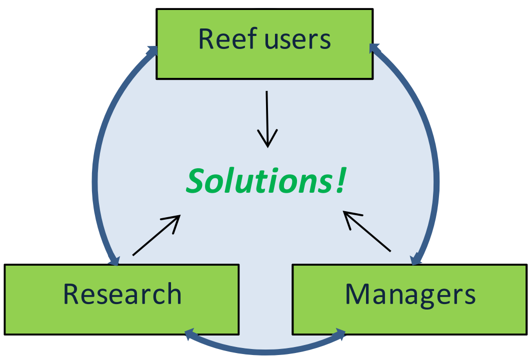


Figure 4.1:
Working together on resilience strategies
Redrawn from Score (2008)

Ocean warming and acidification cannot be effectively addressed at local level alone, but reef managers and reef users can help make coral reefs and the human communities that depend on them more resilient to climate change-related stresses. FRRP has employed the concept of resilience since 2005 to identify coral reefs that will be best able to withstand climate change impacts, and to develop resilience-based reef management and reef use strategies that will maximize protection of resilient reefs and enhance the viability of those that are less resilient (Bergh 2009, p 29).

No one at the reef resilience conference disagreed that climate change is real, coral reefs are imperiled, and climate change is already affecting reefs. Furthermore, NOAA has been cooperating closely for several years with the Great Barrier Reef Marine Park Authority

(GBRMPA) in Australia, initially through its Coral Reef Watch and its then Ocean and Coastal Conservation Policy Advisor, Roger Griffis. NOAA and GBRMPA agree on climate change.

Paul Marshall, GBRMPA's climate change director, presented the conference with the message that the Great Barrier Reef is being affected by climate change, that action is urgently required with a principal strategy to maximize resilience, and that GBRMPA is taking action. He noted that the Australian reef ecosystem is being imperiled especially by rising sea temperatures and sea levels, and by changing ocean chemistry – though also by rising storm frequency and intensity, precipitation, drought and runoff, and changing circulation (Marshall 2008). An 800-page vulnerability assessment covering all species, species groups and habitats from coast to ocean should leave no one in doubt that the Great Barrier Reef World Heritage Area is "under threat as never before" – to quote the foreword to that volume (Johnson and Marshall 2007).

The coordinator of the NOAA Coral Reef Watch agreed with the assessment (Eakin 2008) and presented detailed evidence of rising thermal stress in corals, before recommending the Australian reef managers' guide (Marshall and Schuttenberg 2006), the publication of which was supported by NOAA and the International Union for Conservation of Nature (IUCN). He even hinted at "a reef manager's guide to ocean acidification", though this possibility may still belong to an uncomfortably distant future.

Eakin commended a number of other efforts supporting the management of coral reefs, including the Florida Keys Coral Bleaching Early Warning Network, Bleachwatch, a cooperation between MOTE Marine Laboratory and FKNMS. It is modeled on a similar program in the Great Barrier Reef, established in 2002 during a mass bleaching event.

The Florida Keys version of Bleachwatch was the subject of a special presentation at the conference (Bartels and Walter 2008). The early warning network has two streams:

- Environmental monitoring of climate, remote sensing, and in-situ data from four reefs along the Keys and Pulaski Shoal west of Key West (MOTE and FKNMS/NOAA)
- The Bleachwatch observer network (MOTE, FKNMS and TNC).

The outcome is synthesized data and observations, and reports on current conditions to FKNMS/NOAA.

The observer network has three components:

- Community: Anyone, including residents, tourists, pilots, "any eyes on the water"
- Professional: Dive operators, dive clubs, marine life collectors and others, after completing a short training course
- Scientific: Federal, state, private and academic researchers (FKNMS Damage Assessment and Restoration Program (DARP) and other staff, Fish and Wildlife Research Institute (FWRI), continuing scientific surveys; FRRP, others).

In 2007, the Florida Keys Bleachwatch received 264 reports from >50 volunteers reporting (out of >100 trained to date). At least 25 volunteers reported every two weeks, and eight current conditions reports were distributed. It reported "great relationships with several organizations".

A study of coral resilience in the face of global climate change (Woesik 2008) stressed the need for better understanding of the processes for coral cover change: connectivity, recruitment, post-settlement mortality, growth, heating, fragmentation, mortality. Woesik concluded:

1. Projected changes in climate may drive temperature and seawater chemistry to levels outside the envelope of modern reef experience.
2. Coral tolerance during periods of high sea surface temperatures depend on local light conditions, water flow rates, colony size and shape, and species.
3. Some reef organisms will adapt to climate change more than others – some will be winners, some will be losers, a point also made by Score (2008) and others.
4. Increase desirable states by increasing capacity of the *system* to absorb disturbances maintaining key processes.

In conclusion, resilience has three components (Score 2008). *Resistance* is the ability of corals to resist negative impacts of stress. *Tolerance* is the ability of corals that suffer negative impacts to rebound and live. *Recovery* means that dead corals are replaced by live ones rather than macroalgae. She recommended five general management strategies and one set relating to fisheries management in the interest of resilience:

1. *Education, outreach, awareness and appreciation strategies* including communication of key reef resilience and climate change themes
2. *Research and monitoring strategies* including better integration of DRM (disturbance response monitoring) with other ongoing and new research and monitoring
3. *"Best reef use practice" strategies* (for example for diving, and fishing on and near reefs)
4. *Management strategies that don't need new regulation* (navigation aids, mooring buoys, law enforcement focused on resilient reef areas and highly vulnerable but valuable reef areas, and using FKNMS authority to close sick reefs to the public)
5. *New regulatory strategies* including general (rotate closures, boating licenses, regulations to reduce GHG emissions), tourism-oriented (required environmental education, best practices license), zoning-oriented (marine zones governed by resilience concepts), coastal construction-oriented (timing of sediment producing construction, no dredging, no beach renourishment), water quality-oriented (centralized sewer, storm water treatment, pesticides), and law enforcement (focus on resilient reefs, increase presence, undercover inspectors)
6. *Fishing management strategies* (reduce ghost traps; develop a reporting system for boaters to notify trap fishermen and authorities of accidentally cut trap lines; fully implement the lobster trap reduction plan).

A climate action plan for South Florida: As this report was being finalized, the FRRP published a concise climate action plan for 2010-15 for the FKNMS, adjacent national parks and the coral reef areas to the north which together comprise the Florida Reef System. Proposed actions, forty in all, were based on the 2008 Conference findings and a review of relevant literature (FRRP 2010). The regional director of NOAA's Office of National Marine Sanctuaries, Billy Causey, warmly welcomes the plan in a foreword which encapsulates the spirit of constructive cooperation in the area in the face of escalating threats from climate change:

"This Action Plan is the culmination of 5 years of collaborative effort amongst a broad spectrum coral reef scientists, managers, and user groups with some of the most informed individuals in their respective fields. The plan recognizes the need for a holistic approach across the geographic range of Florida's coral habitats given the inevitability of warmer, more acidic oceans, and rising sea levels. It is grounded in the concept of "resilience", or ability of the ecosystem to bounce back from impacts. ..."

4.2.6 POLLUTION

The scenario-planning workshops on impact on reef from the north:

- Coral bleaching, associated disease history, and land-based pollution and other influences. How to maximize coral resilience in the face of pollution from external sources – major mainland rivers and the Everglades.
- Turkey Point Nuclear Station (Biscayne Bay, 25 miles south of Miami) is being expanded. It uses Bay water for cooling but the question was raised where it flows from the cooling canals. (According to the Florida Power and Light website a separate supply of water that cools the turbine steam supply for reuse comes from a system of 36 interconnected canals. The canals act like a giant radiator to cool the water in a two-day, 168-mile journey before it is circulated back to the condenser for reuse.)
- Outfalls from major cities in the north are mandated to shut down by 2025, but funding is a problem. On April 30 2008, the Florida Legislature passed a bill to end dumping of partially treated sewage onto the reefs of Southeast Florida. Wastewater must meet the higher standard of Advanced Wastewater Treatment by 2018 and achieve at least 60% reuse of the wastewater by 2025. New or expanded ocean outfalls will not be allowed and use of the pipes will be prohibited after 2025. The six ocean outfall pipes in Palm Beach, Miami-Dade and Broward County discharge a daily average of about 360 million gallons of treated wastewater to the ocean near the coral reefs of Southeast Florida.

Wastewater and sewerage in the Florida Keys:

- While there is a mandate to put in sewers, progress in Monroe County is running behind the mandate. The State of Florida requires Monroe County to comply with requirements to provide centralized sewer facilities throughout the Florida Keys by July 1, 2010. The Sanitary Wastewater Management Plan was approved by the Board of County Commissioners in June 2000.
- In November 2007, implementation of the Keys Wastewater Plan was estimated to cost $939 million to complete. Approximately $264 million would have been spent by the end of September 2008 to retrofit Monroe County with 2010 compliant wastewater treatment. Approximately $50 million of this cost was funded through grants from the State of Florida. The remaining cost to implement the Keys Wastewater Plan was estimated at $675 million. The funding gap between project costs and available funding was $336 million.

- Sewerage progress: Key West is fully sewered (problem here is wastewater runoff); Key Colony Beach has been for 25 years; Layton recently; North Key Largo is getting close but the problem is the unincorporated areas, 70% of which was said not to be sewered.

Individual solutions to water shortage:

- Water supply is again seen as the limiting factor for growth and development. Suggestions included: Composting toilets using no water and provide compost, using grey water for irrigation, and rainwater tanks.

Other government management issues:

- Is particular mandated government spending becoming irrelevant due to climate change and sea-level rise?
- Allocation system for new residential developments determined by 24-hour hurricane evacuation time rather than environmental issues
- Inequities in application of stormwater runoff rules
- Lack of federal funding for authorized projects
- Support, or lack, of sustainable building standards such as use of solar energy
- Lack of government incentives to use appropriate technologies
- Dependence on wastewater treatment in Miami-Dade, and on own investment in Monroe County.

4.2.7 Economy, tourism, and diversification potential

Economy

One of the main themes in the workshops was population change. Abstracting from the temporary respite due to the recession, it is becoming less affordable to live in the Keys with rising property values. They cause many locals to sell out at high prices, especially for waterfront property. People moving in are either buying for investment to resell, or are very wealthy buying their third or fourth homes, including Europeans.

One effect is loss of people who want to improve the community, being replaced with people who have no emotional investment. Young people are leaving. It is important to attract people who are concerned about the Keys community and environment, people who can live and work here full-time. The preservation of lifestyle is associated ultimately with the reef. Polarized wealth distribution is a big threat.

The economy has gone "full-time". One workshop participant said: "25 years ago we had a part-time economy. From Labor Day until almost Christmas you could just about sleep on US 1 without fear of getting run over. We now have a full-time economy with a geometric rise in bed taxes." (*This observation is not borne out by statistical data, as shown in Chapter 6.*)

Energy efficiency: Carrying capacity – does sustainable growth equal redevelopment while protecting our natural areas and achieving efficiency of energy and water use? Energy crisis and potential of alternative energy. Importance of people living with alternative energy in No Name Key.

Role of Rate of Growth Ordinance (ROGO) – limited building permits and building heights, and land use plan.

In the Lower Keys, another linchpin apart from tourism is the military economy. “Something that would really rock the foundation of this community would be a pullout of the military. It would create opportunities. But it would be a significant challenge for this economy and for the culture of this place.”

Tourism

Tourism is the economic engine. There is a transition to an upscale economy but lack of upscale services and facilities. First-class restaurants are scarce. The need remains to import people by bus from the mainland to do the sort of mundane jobs people down here aren't taking.

The Florida Keys are a getaway destination for “millions” from Miami. Rising fuel prices will deter long-distance travel (both road and air). Refer Chapter 6 for some basic statistics.

Key West is special – historic buildings and culture, which attracts a large and diverse part of total tourism. There appears to be a source of disunity in the Keys associated with the perceived “historical” role Key West assigns to itself, which causes it to set itself apart from other Keys communities. Chapter 6 shows that its growing role is demonstrated by the most recent NOAA visitor survey (2007-08) showing a decline in sea-based tourist activities relative to land-based activities.

Key West is a destination for cruise ships. People in the wintertime also come down from the north through the intra-coastal waterways and spend the winter in the Keys, though mostly they go through to the Bahamas.

These notes are supplemented by statistics shown in Chapter 6. The socioeconomic implications, however, cannot be entirely captured by numerical data but rely also on the strengths and weaknesses of the information extracted from the workshops.

Diversification potential

Like the resilience planning for the physical environment, socioeconomic resilience planning also has its place.

One topic canvassed in the workshops was what industries might be suitable for the Florida Keys if tourism declined. While referring to Appendix 2 for detailed comments, this is a selection of the suggestions:

General: We need to do scenario planning in a structured environment: Where do we want our community to be? What do we want our economy to look like? Something that's stable year-round. We want people to be able to live and work here and prosper here 12 months.

Diversification is compatible with addressing climate change. Primary concerns are economic diversity, infrastructure, and lifestyle (which is closely related to the reef). It is important that the character of the community is retained, and to attract those who are concerned about our community and environment rather than Costa del Sol or the Azores.

Environmentally related educational activities: Marriage between marine environment and marine science programs in universities. “We are a living laboratory for climate change.”

Renewable energy:

- Without a renewable energy policy the Keys' economic engine will stop if we continue to depend on drive-down traffic, cruise ships, resorts and vacations with people that have disposable income.
- Florida Power & Light is the largest producer of wind power and it's in Arizona. The Keys don't have the constant wind required.
- Tidal power: We do have constant tides and waves. Some people here are investing in a revolutionary approach to harness the power of the ocean. But we need a political mind-set and an agenda that is driven by looking at those alternatives as opposed to the current oil regime.
- Solar energy has huge potential: new solar technologies, plus longer-lived units being developed. Very little solar power has been installed in the Keys to date compared with that potential. *Note: This refers to local installation only, rather than producing panels.*
- Biodiesel from algae. A prominent scientist participating in the workshops said, "Of all the different terrestrial sources of good oil-producing plants that can produce oil for biodiesel, algae trump them by a thousand percent."

4.2.8 Role of Education and Outreach

The workshops made a great number of suggestions hard to classify but in their totality illustrating the scope of possibilities (for detail see Appendix 2):

- Education – communication – enforcement, all three are essential. There is a lack of law enforcement. Boat license conditions should be strengthened, and there should be more efficient promotion of no-take areas. Educate locals in sustainable behavior in community's interest. Educate locals as well as visiting boaters on limiting reef damage.
- Encourage environmentally aware tourist attractions; establish an ecotourism education center backed by educational institutions. Involve people already here (dive industry, FKNMS). Programs like *Green Lodging*: involve guests as part of solution – good for business too.
- There are problems educating people from diverse cultures, especially older people. Reach the parents through the children. Educate people on the success of things.
- Promote alternative energy for local use: biodiesel for boats, solar panels, tie to global change. Promote recycling campaigns. Support people leading by example such as GLEE.
- Anticipate impact of climate change (warming, sea level) to help support resilience. Adopt a long-term planning view. Learn from past mistakes.

4.3 Integrated Coastal and Marine Management

4.3.1 Sanctuary Characteristics

It is not the role of this project to provide detailed descriptions of existing institutions, but rather to raise issues relevant to the overall subject of *Climate Change and the Florida Keys*. The following three paragraphs summarize the character of the Sanctuary from the management plan (FKNMS 2007, *About this document*):

“The Florida Keys National Marine Sanctuary extends approximately 220 nautical miles southwest from the southern tip of the Florida peninsula. The Sanctuary’s marine ecosystem supports over 6,000 species of plants, fishes, and invertebrates, including the nation’s only living coral reef that lies adjacent to the continent. The area includes one of the largest seagrass communities in this hemisphere. Attracted by this tropical diversity, tourists spend more than thirteen million visitor days in the Florida Keys each year. In addition, the region’s natural and man-made resources provide livelihoods for approximately [73,000] residents.

The Sanctuary is 2,900 square nautical miles of coastal waters, including the recent addition of the Tortugas Ecological Reserve. The Sanctuary overlaps six State parks and three State aquatic preserves. Three national parks have separate jurisdictions, and share a boundary with the Sanctuary. In addition, the region has some of the most significant maritime heritage and historical resources of any coastal community in the nation.

The Sanctuary faces specific threats, including direct human impacts such as ship groundings, pollution, and overfishing. Threats to the Sanctuary also include indirect human impacts, which are harder to identify but seem to be reflected in coral declines and increases in macroalgae and turbidity. More information about the Sanctuary can be found in this document and at the Sanctuary’s web site: http://floridakeys.noaa.gov.”

It is striking that the perceived threats when the management plan was developed were associated with direct human impacts rather than the impact of climate change. This has definitely changed, as evidenced by a presentation in August 2009 on ocean acidification by the Regional Director for NOAA’s National Marine Sanctuary Program to the bimonthly Florida Keys National Marine Sanctuary Advisory Council (SAC) meeting (Causey 2009).

4.3.2 Sanctuary management style

“Integrated management” is the best way to describe how the Florida Keys National Marine Sanctuary works with local, state and other federal agencies to foster compatible management strategies and policies, based on multiple jurisdictions. The FKNMS itself is one of 13 marine protected areas managed by NOAA's National Ocean Service (NOS), ranging from the Pacific (Hawaii and American Samoa) to the Florida Keys and three other areas along the Atlantic coast of the United States.

The description here focuses naturally on the FKNMS and its efforts to value and preserve the marine ecosystem and improve its resilience in a manner that takes all the ecological, socioeconomic and demographic interdependencies into account. The next section (4.4) highlights the role of volunteer groups and non-government organizations in the area.

The key issue facing sanctuary management in conditions of threatening climate change was discussed in Section 4.2.5: enhancing coral reef resilience in the effort to improve reef health. This matter will become increasingly urgent as climate change gathers pace and affects sea surface temperatures, sea levels, and ocean chemistry.

The strong impression formed during this project is that an *adequately funded* FKNMS is excellently equipped, institutionally and through the expertise of its management and staff, to deal with climate change as long as the change remains *manageable*. Note the two provisos: adequate funding and climate change remaining controllable. Funding sources are complex and no trends have been identified – however the case remains that the aggravated circumstances as climate change accelerates will put further pressures on the FKNMS.

This author claims no specific expertise in sanctuary management, but offers his views as an observer. The integrated management style across all three levels of government, and the consultative role of the Sanctuary Advisory Council and the mature manner in which information and advice is exchanged between the FKMNS management team and SAC is impressive. The quality of leadership and information exchange can only be applauded.

Funding does have to be an issue, however. Clearly, the increasing danger signals from climate change and the gaps that remain in knowledge at all levels are challenges that must be met. This will require increased budgets.

Integrated management itself is also an issue because the reef ecosystem is managed by different government agencies with specific spatial jurisdictions. Fisheries are managed by the Florida Fish and Wildlife Conservation Commission and two federal fishery management councils (US South Atlantic and Gulf of Mexico). Different fishing regulations can also apply in the Florida Keys National Marine Sanctuary (FKNMS), in three national parks (Biscayne, Everglades, Dry Tortugas) and four National Fish and Wildlife Refuges (Department of Interior); and in the John Pennekamp Coral Reef State Park managed by the Florida Department of Environmental Protection (Ault et al. 2005, p 600).

Finally, Florida Bay is 85% part of the Everglades National Park with the remainder mainly under FKNMS. The health of the Bay is vital for the rest of the Florida Keys, as discussed in Section 5.4.4.

4.3.3 The Sanctuary Advisory Council – role in integrated management

The SAC was established by the US Secretary of Commerce in 1992 to provide advice to the Sanctuary superintendent and the Director of the Office of Coastal and Aquatic Managed Areas of the Florida Department of Environmental Protection. SAC members are appointed by NOAA, in consultation with the State of Florida. Members include representatives of nominated commercial and recreational user groups (commercial and recreational fishermen, the dive industry, and the boating industry), conservation and other public interest organizations, scientific and educational organizations, and members of the public interested in the protection and multiple-use management of Sanctuary resources. (The website, http://floridakeys.noaa.gov/sac/welcome.html, shows the current membership and the minutes of all bimonthly meetings held since the beginning of 2000 – well worth visiting for current issues and a historical perspective.)

The issues were taken up by Daniel O. Suman of the University of Miami relatively early in the life of FKNMS (Suman 1997). He noted that SAC was “a new experiment in ‘citizen governance’ of the Sanctuary” (p 296). All the signs are that constructive cooperation between SAC and FKNMS management has continued into 2010.

SAC is reported to have played an important role in the planning process since its formation in February 1992. It played a significant and strong role in the development of the first final FKNMS management plan, dated September 1996. In the process, it elevated some issues, such as Florida Bay restoration, that had not been targeted by the Inter-Agency Core Group which was formed in 1991 representing three State departments and the Florida Governor’s office. Representing most of the marine resource user groups, the SAC was able to develop an acceptable and feasible plan for the debated sanctuary zones (Suman 1997, p 297)

Integrated management also characterizes the cooperation between state and federal authorities. After the Congressional designation of the FKNMS in 1990, a close partnership between the Federal Government and the State of Florida has characterized sanctuary planning and development of the management plan.

4.3.4 A VOTE ON RESILIENCE STRATEGIES

The FRRP conference in April 2008 described in Section 4.2.5 surveyed a large number of potential resilience strategies to find the most popular or acceptable ones. Figure 4.2 shows the top 10 preferences according to the conference participants. Four of the ten preferences were of a regulatory nature (shown in blue), three research and monitoring (brown), two voluntary "best use practices" (pink), and only one education and outreach (orange). This result are at least indicative evidence of reef managers' thinking. The ten strategies received between 49 and 37 votes from the conference participants, while another 15 received between 21 and 35, and 33 between 10 and 19 – leaving the remaining 100 potential resilience strategies with single-digit votes at the conference (refer FRRP 2008).

1	Devise a comprehensive plan for marine zoning based on reef resilience principles, best available biophysical and social science and reef user input. Account for environmental protection and sustainability of commercial and recreational uses. (Reg)
2	Create a boating license similar to a driver's license (Reg)
3	Encourage dive tour operators and other groups and users to get involved in monitoring. BleachWatch, MEERA etc (possibly model on Great Barrier Reef's "Eyes on the Reef" program) and integrate these into a centralized, user-friendly reporting system (R&M)
4	Keep lobster and crab traps away from living corals (Vol)
5	Continue examining relationships between local environmental conditions (e.g. UV/light, water quality, currents, doldrums, and other contaminants, etc.), biological and physical environment and bleaching to better understand reef resilience to climate change. Expand existing efforts focused on the Keys to the mainland (R&M)
6	Blue Star: Dive and snorkel operators get certified, divers and snorkelers use certified operators. Includes environmental and climate change briefing and general green practices (Vol.)
7	Increase law enforcement presence in general and focus effort on resilient reef areas (Reg)
8	Policy makers. They have the power (Edu)
9	Regularly communicate analytic results to reef managers and the public to best address their needs (R&M)
10	User fee for all reef users (Reg)

Potential strategies represented: Regulatory (1,2,7,10). Research and monitoring (3, 5, 9). Voluntary "best reef use practices" (4, 6). Education, outreach, awareness and appreciation (8). Source: FRRP (2008)

Figure 4.2: Top 10 votes among 158 potential resilience strategies for Florida Keys, April 2008

4.3.5 MARINE ZONING

There are currently five current zoning types in the FKNMS area: Sanctuary Preservation Areas (SPAs), Ecological Reserves (ERs), Special Use Areas, Research Only Areas, and Wildlife

Management Areas. Approximately 6% of the total FKNMS area, mainly in the Dry Tortugas, is closed to all extractive uses, or "take" – this is insufficient according to a special Sanctuary Advisory Council workshop which reported in March 2008 (FKNMS-SAC 2008). The workshop advocated new and larger SPAs, and no-take buffers around existing SPAs and/or more ERs.

The circumstances may be different, but the low proportion of Marine Protected Areas (MPAs), especially in the Florida Keys area itself, contrasts with actions taken to protect the Great Barrier Reef, where the Australian Government increased the protected area from 4.6% to 33.3% in 2004, making the Great Barrier Reef Marine Park the largest protected sea area in the world. The recommendations of the SAC workshop were debated by the bimonthly SAC meeting on July 11, 2008, although no firm decisions were taken.

Climate change will have increasing and mutually reinforcing impacts on ocean warming, ocean acidification, sea-level rise, the variations in ocean-atmosphere interactions and ocean circulation (including the El Niño-Southern Oscillation and Pacific Decadal Oscillation), increasing storm intensity, and worldwide changes in the amount, intensity, frequency and type of precipitation which will increase the salinity in the shallower parts of the tropical and subtropical oceans (Keller et al. 2009).

Climate change, these authors continue, interacts with "traditional" stressors of coral reefs and other ecosystems: land-based pollution sources, overfishing and destructive fishing practices, non-indigenous and invading species, and disease. They conclude that options for MPA management must be taken to ameliorate existing "traditional" stressors, to protect potentially resilient areas, and to develop MPA networks.

The section of the paper dealing with MPA networks says it all: "For both terrestrial and marine systems, species diversity often increases with habitat diversity, and species richness increases with habitat complexity; the greater the variety of habitats protected, the greater the biodiversity conserved. High species diversity may increase ecosystem resilience by ensuring sufficient redundancy to maintain ecological processes and protect against environmental disturbance for both terrestrial and marine systems. This is particularly the case in the context of additive or synergistic stressors. Maximizing habitat heterogeneity is critical for maintaining ecological health, thus MPAs should include large areas and depth gradients. By protecting a representative range of habitat types and communities, MPAs have a higher potential to protect a region's biodiversity, biological connections between habitats, and ecological functions" (Keller et al. 2009, "Develop MPA networks").

Significantly, a comprehensive marine zoning plan based on resilience principles was the top strategy voted by the participants in the 2008 FFRP conference (Figure 4.2).

4.4 COMMUNITY ORGANIZATIONS

Local community organizations are important in the Keys area. Among the most prominent are Green Living & Energy Education (GLEE) and SFFFK (Sanctuary Friends Foundation of the Florida Keys). Since its creation in 2003, GLEE has been a powerful catalyst for climate change mitigation at the local level (Bergh 2009). Other local organizations include Last Stand, organized to promote, preserve, and protect the quality of life in the city of Key West, the Florida Keys and their environs, with particular emphasis on the natural environment.

The Key Deer Protection Alliance and FAVOR (Friends and Volunteers of Refuges) have special missions protecting endangered species in the Florida Keys.

Reef Relief, founded in 1987 in Key West, has a long history of preserving and protecting living coral ecosystems, including installation of mooring buoys, creating coral nurseries, and conducting ongoing surveys of coral health leading to the discovery of several new coral diseases. The organization now operates in many other areas apart from the FKNMS area.

Other organizations of local importance and beyond include Chambers of Commerce in Key Largo, Islamorada, Marathon, Lower Keys, and Key West. While primarily serving commercial interests, these are influenced by an environmentally sensitive tourism industry. GLEE in 2009 launched a Certified Green Business program, based on a pilot process in which the Lower Keys Chamber of Commerce and Visitor Center became one of only two member operations to qualify (http://www.keysglee.com/index.cfm/green-business-directory/ shows the number rising to nine by July 11, 2010). The GLEE initiative provides "an easy to follow, step-by-step, DIY greening process. Once the required measures have been implemented, an on-site assessment is conducted. If all standards are met, the business becomes certified, a recognition that includes several rewards and incentives designed to inspire businesses to get with the program."

Some local organizations have broader geographical links. Beyond the Florida Keys, the Florida Climate Alliance fosters State leadership in mitigating and adapting to the challenge of global warming. The FCA is itself part of the Southeast Coastal Climate Network, which consists of coastal organizations working towards climate solutions from Louisiana to Maryland.

Internationally, NGOs focused on climate change mitigation include the international ICLEI – Local Governments for Sustainability, founded in 1990. Its growing membership includes over one thousand cities, towns, countries and their associations.

Of the worldwide non-government organizations that are active in the Florida Keys, TNC (The Nature Conservancy) has already been mentioned. It started work in the Keys in 1971 and opened its first office there in 1987. WWF has also traditionally been an important presence.

Audubon of Florida operates the Tavernier Science Center in the Upper Keys, concentrating on estuarine and marine research. TSC scientists are currently studying the flow of freshwater into Florida Bay and the impacts the diversion of water has had throughout the Everglades ecosystem.

The non-government and volunteer organizations, as well as working on similar causes or in association with the FKNMS and others, are finding increased opportunities for cooperation as government authorities at all levels develop new approaches to dealing with environmental issues. Climate change mitigation is being addressed by institutions from international to municipal level. "Non-regulatory bodies like the IPCC, the US Mayors Climate Protection Task Force, the Florida Energy and Climate Commission, Monroe County's Green Initiatives Task Force and local government "green teams" for the City of Key West, City of Marathon, City of Key Colony Beach, City of Layton, [and] Islamorada, Village of Islands, play an increasing role in developing and tracking mitigation actions." (Bergh 2009)

5 BIOPHYSICAL RESEARCH

5.1 OVERVIEW

Previous chapters have commented on a range of physical research matters including sea-level rise and marine sanctuary management which are subjects of intensive environmental research undertaken over a long period, focusing on reef health. We now focus on coral cover and trends in commercial fishery landings. Section 5.3 shows statistics, while Section 5.4 notes some of the ongoing work on marine life biology and ecology around the Florida Keys.

5.2 CORAL COVER AND HEALTH

Coral cover is the proxy for coral reef condition according to Woesik (2008), whose presentation at the FRRP conference included a chart showing coral cover in the Caribbean falling from over 50% in 1977 to less than 10% in 2000. The situation may have deteriorated even more dramatically (Richardson and Voss 2005): While widespread occurrences of total coral colony mortality, partial mortality, population decline, and apparent decreases in coral recruitment have been reported on many reefs, these problems are particularly prominent in the wider Caribbean where it has been estimated that coral cover has declined by 80% over the past 30 years.

Anecdotal evidence includes older participants at the 2008 scenario-planning workshops (Appendix 2) recalling the 1950s and 1960s. They said that large reductions of coral cover have also taken place in the Florida Keys. Voss (1988) supports these impressions.

Table 5.1: Coral cover in the Florida Keys and Dry Tortugas

	Lower Keys	Middle Keys	Upper Keys	Total FKNMS	Dry Tortugas
Stations →	46	27	28	101	12
1996	15.3%	7.3%	12.4%	12.3%	
1997	14.7%	7.2%	11.4%	11.8%	
1998	12.6%	6.3%	9.1%	10.0%	
1999	9.3%	5.3%	7.3%	7.7%	18.9%
2000	9.6%	5.4%	7.1%	7.8%	17.4%
2001	9.3%	5.5%	7.1%	7.7%	17.4%
2002	8.9%	5.9%	7.2%	7.6%	14.1%
2003	8.7%	5.5%	7.2%	7.4%	13.4%
2004	7.9%	5.0%	6.9%	6.9%	11.7%
2005	8.0%	5.6%	6.6%	7.0%	11.4%
2006	7.2%	5.0%	5.9%	6.3%	8.8%
2007	7.0%	5.1%	7.0%	6.5%	9.8%
2008	6.8%	5.1%	6.9%	6.4%	10.3%

Source: Coral Reef Evaluation and Monitoring Project (CREMP): From worksheet CREMP_FKNMS_PCgrp_9608_101stn

Table 5.2: Stony coral cover, Florida Keys, by habitat

	Hardbottom	Offshore deep	Offshore shallow	Patch
Lower Keys				
1996	1.2%	7.6%	16.9%	24.8%
1997	1.1%	7.9%	16.4%	22.9%
1998	1.4%	5.3%	13.2%	22.4%
1999	1.4%	4.2%	7.3%	19.2%
2000	1.2%	4.3%	7.4%	20.1%
2001	2.3%	4.4%	6.9%	19.0%
2002	0.5%	4.2%	7.4%	17.6%
2003	0.6%	3.9%	7.3%	17.5%
2004	0.4%	3.1%	7.0%	16.0%
2005	0.6%	3.2%	5.5%	17.9%
2006	0.3%	1.9%	4.9%	17.2%
2007	0.4%	2.3%	4.9%	16.3%
2008	0.2%	2.4%	4.7%	15.7%
Middle Keys				
1996	3.8%	4.1%	4.6%	15.8%
1997	3.8%	4.8%	4.2%	15.6%
1998	2.9%	3.4%	3.7%	14.4%
1999	3.2%	3.0%	2.0%	13.2%
2000	2.6%	2.8%	2.0%	14.2%
2001	2.9%	3.0%	1.9%	14.1%
2002	2.3%	2.7%	2.1%	16.3%
2003	2.7%	2.9%	1.8%	14.7%
2004	1.9%	2.5%	1.7%	13.6%
2005	2.5%	2.7%	1.8%	15.1%
2006	1.9%	2.3%	1.4%	14.2%
2007	1.8%	2.0%	1.2%	15.3%
2008	1.8%	2.2%	1.7%	14.3%
Upper Keys				
1996		7.4%	12.1%	16.3%
1997		6.1%	11.2%	15.2%
1998		3.5%	8.3%	14.0%
1999		3.4%	5.9%	11.9%
2000		3.6%	5.9%	11.3%
2001		2.9%	5.6%	12.2%
2002		3.0%	5.6%	12.2%
2003		3.1%	5.2%	12.6%
2004		2.7%	4.9%	12.5%
2005		2.7%	4.8%	11.8%
2006		2.3%	4.1%	11.0%
2007		3.2%	4.5%	13.2%
2008		3.0%	4.8%	12.7%

Source: CREMP worksheets

Comprehensive hard evidence based on constant surveying, however, is only available since 1996, through the Coral Reef Evaluation and Monitoring Project (CREMP) which is part of the FKNMS Water Quality Protection Program and is administered by the Florida Fish and Wildlife Research Institute (FWRI). The mean stony coral cover fell from 12.3% in 1996 to 6.4% in 2008, though it seems to have stabilized over the last three years (Table 5.1). The same applies to each section of the Keys (Lower, Middle, Upper), and the Dry Tortugas. The deterioration was worst in the Lower Keys and least pronounced in the Middle Keys, which even in 1996 was only 7.3%, from which it has fallen further to 5.1%.

Besides monitoring coral cover, CREMP has noted a slight upward trend in the number of stations with the herbivorous sea urchin *Diadema antillarum* (see Section 4.2.5), though the percentage of stations remains modest at around 10%. There is a slightly more positive development in the incidence of coral disease, another object of CREMP monitoring. The incidence of black band disease peaked in 1998, and white disease (white plague, white band and white pox) and other diseases including dark spot, yellow band and idiopathic diseases have been generally declining. However, the incidence of white disease increased significantly between 2005 and 2006, to more than half the stations.

The 1983-84 Caribbean-wide mortality of *Diadema antillarum* was followed by a second mortality event in the Florida Keys in 1991. The demise of this once ubiquitous herbivore is recognized as a factor contributing to wider Caribbean reef change during the past 25 years. A survey of 786 sites from the northern extent of the Florida Reef Tract to the Dry Tortugas, including two National Parks and the FKNMS, found that while pre-1983 densities were as high as five individuals per m^2, surveys since 1999 at a range of depths show that densities are still well below one individual per m^2 (Chiappone et al. 2008).

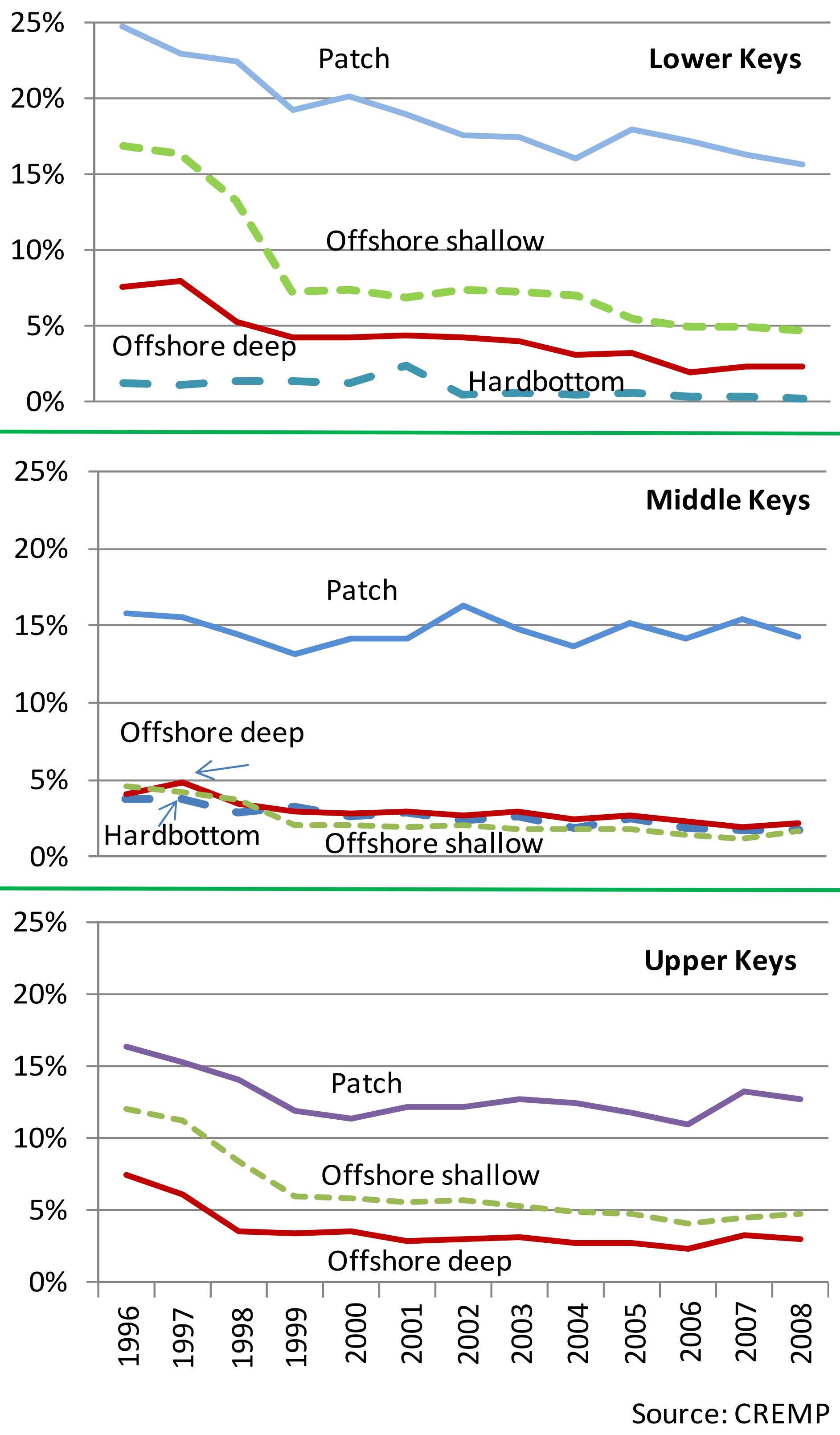
Coral cover is highest on patch reefs, in the Upper, Middle, and Lower Keys. Between 1996 and 2008, patch reef cover declined most strongly in the Lower Keys, but remained slightly higher than in the two other regions (Table 5.2 and Figure 5.1). The Lower Keys also lost the most cover from deep and shallow offshore reefs and in hardbottom areas, which cover some 40% if the seafloor in the shallow waters of the marine ecosystem.

The Dry Tortugas has also lost coral cover despite its isolation from coastal development (Table 5.3). Patch reef cover is much less than in the Florida Keys, while the cover remains significantly higher in offshore deep areas. These observations were taken directly from the CREMP source shown below Table 5.1.

Other techniques have been used to measure the change in coral cover, including the use of satellite data. Landsat images from 1984 to 2002 were adapted to measure habitat changes for eight coral reefs in the FKNMS (Palandro et al. 2008). While the results differed from reef to reef, the coral habitat decline for all the reef sites was 61% over 18 years (an average annual loss of 3.4%). CREMP observations for the same reefs were correlated with these results and no statistically significant difference found.

Another important research effort in the Florida Keys into coral health and cover is headed by Steven Miller, an ecologist with the University of North Carolina-Wilmington working in Key Largo, and his colleague Mark Chiappone. Miller and Chiappone have taken a different approach from the CREMP team, with a program which is apparently the only one that takes a specific look at conditions inside and outside protected areas. The approach is based on randomly stratified benthic sampling to make it representative of the reef geography of the Keys. Since it began in 1999 it has brought many new insights to bear.

Figure 5.1: Stony coral cover, Florida Keys, by habitat



The declines in abundance of two of the principal Caribbean reef-building corals, Staghorn coral (*Acropora cervicornis*) and Elkhorn coral (*A. palmata*), are often-cited examples of the changes in western Atlantic reefs that have occurred during the past several decades. The causes of these declines, which began in the late 1970s, include large-scale factors such as coral bleaching and disease, especially white band disease which was in evidence long before other misfortunes hit, such as the near-eradication of *Diadema antillarum* in 1983-84 and the first major bleaching events in the Florida Keys.

Table 5.3: Stony coral cover, Dry Tortugas

	Offshore deep	Patch
1999	23.6%	9.5%
2000	22.1%	8.0%
2001	23.3%	5.8%
2002	18.3%	5.6%
2003	18.0%	4.2%
2004	16.6%	1.9%
2005	16.3%	1.6%
2006	12.6%	1.1%
2007	14.0%	1.2%
2008	14.5%	1.8%

Source: CREMP

Two whole-reef investigations at the Looe Key National Marine Sanctuary in 1983 and 2000 showed a 93% decline in the total area of live *A. palmata*, and a 98% decline for *A. cervicornis* (Margaret Miller et al. 2002). The decline would have been even worse but for a loss of only 25% for *A. palmata* in one of the six sections of the reef, while losses exceeded 97% in the five other sections. Similarly, for *A. cervicornis*, one section showed a decline of 51%, and all the other sections declines of 99-100%. In contrast to the Indo-Pacific, which is host to a plethora of acroporid corals, *A. palmata* and *A. cervicornis* have been the major reef-building coral species for most of the past 500,000 years throughout the Caribbean, serving another important ecological function of coral reefs by providing habitat for numerous reef fish species.

While the 2002 paper quoted above suggested that the dramatic loss at Looe Key Reef was representative of the Florida Keys, an intensive survey undertaken more recently by Steven Miller and colleagues (Miller et al. 2008) seems to tell a slightly more optimistic story of *Acropora* corals in the Florida Keys. The authors quantified habitat distribution, colony abundance, size, and condition at 235 sites spanning over 200 km. *A. cervicornis* was widely distributed among sites and habitats and was particularly abundant on patch reefs. *A. palmata* was abundant on shallow spur and groove reefs. Although the prevalence of disease is relatively low, both species continue to suffer predation, as well as physical impacts from lost fishing gear. Predicting the future of these corals in Florida requires information about both their present-day ecology and geologic history in Florida.

Bringing the geology into the picture is the theme of Precht and Miller (2007) who note that the ecology of Caribbean and western Atlantic coral reefs has changed dramatically in recent decades especially along the Florida reef tract.

"Whether these recent changes are natural cyclic events or the result of human activities has been a topic of strenuous debate. To address this issue, we asked the question, "Did episodes of reef degradation occur in the past, before the era of human interference, or is the current state of coral reefs unique to our time?" (pp 237-238)

"Because coral reefs are both geologic and biologic entities, it is possible to observe the effects of various disturbances in ecological time, detect historical changes in the paleoecological record, and deduce the multiscale processes behind those patterns. For Florida at least, the present reef community assemblage, highlighted by diminishing *Acropora* populations, is not unique in space or in time." (p 284)

The authors conclude that quaternary reefs in Florida emphasize the resilience of reef ecosystems and the responses of coral species to rapid environmental change in the absence of major human modification of the seascape. These ecological shifts in coral community composition allow us to use the past as a key to predicting the future of reefs in a world now besieged by numerous disturbances from natural and human influences.

5.3 COMMERCIAL FISHERY LANDINGS

Annual surveys of fishery landings by species go back to 1986 and are compiled by the Florida State Fish and Wildlife Research Institute (FWRI). The statistical record covers all significant Florida species by county. Table 5.4 shows the time series for Monroe County, basically the Florida Keys. The "snapper-grouper complex" represents the main commercial

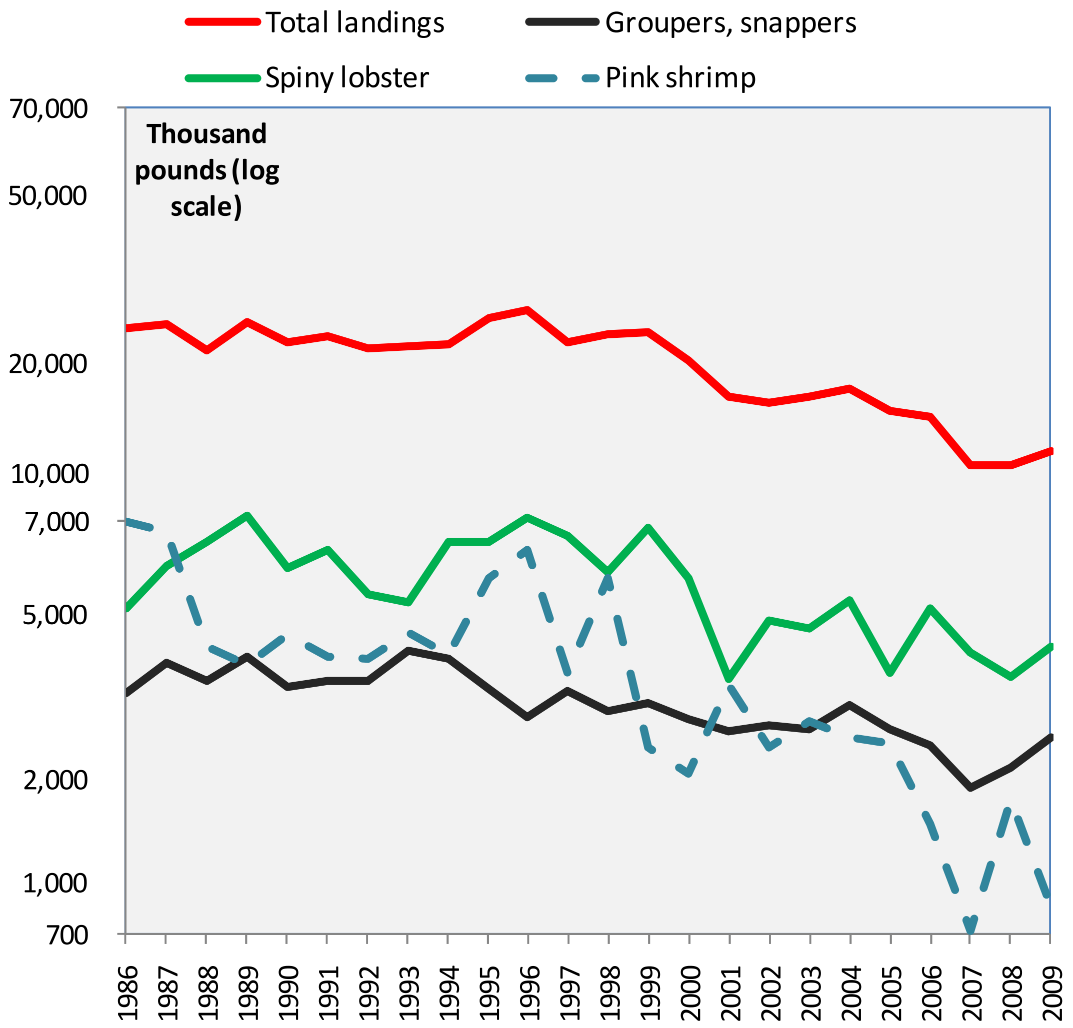
Table 5.4: Annual commercial fishery landings, Monroe County

Thousand Pounds	Groupers, snappers	Other finfish	Total finfish	Spiny lobsters	Pink shrimp	Other in-vertebrates	Total landings
1986	2,679	5,636	8,315	4,333	7,027	936	20,612
1987	3,177	4,749	7,926	5,467	6,601	1,010	21,005
1988	2,896	4,386	7,281	6,263	3,471	1,220	18,235
1989	3,293	5,824	9,116	7,255	3,162	1,619	21,153
1990	2,796	5,168	7,964	5,434	3,725	1,812	18,935
1991	2,885	5,696	8,581	5,999	3,285	1,902	19,767
1992	2,873	5,435	8,307	4,665	3,269	2,049	18,291
1993	3,403	5,218	8,621	4,448	3,764	1,847	18,679
1994	3,273	3,938	7,211	6,239	3,323	1,943	18,716
1995	2,754	5,226	7,980	6,245	5,090	2,546	21,861
1996	2,356	4,934	7,291	7,139	5,969	2,251	22,649
1997	2,727	3,824	6,551	6,461	3,023	2,908	18,943
1998	2,421	3,773	6,194	5,268	5,088	3,290	19,841
1999	2,546	3,969	6,515	6,794	1,995	4,804	20,108
2000	2,328	3,539	5,866	5,115	1,716	4,409	17,106
2001	2,167	3,659	5,826	2,904	2,833	2,514	14,076
2002	2,240	3,336	5,576	4,036	1,993	1,944	13,550
2003	2,199	3,809	6,008	3,851	2,310	1,926	14,094
2004	2,511	3,366	5,877	4,496	2,112	2,214	14,699
2005	2,200	4,439	6,638	3,027	2,038	1,346	13,050
2006	2,011	3,675	5,686	4,327	1,303	1,191	12,506
2007	1,593	2,564	4,157	3,379	719	1,323	9,579
2008	1,783	2,410	4,193	2,955	1,491	990	9,628
2009	2,111	3,227	5,338	3,493	821	772	10,424

Source: Fish and Wildlife Research Institute (FWRI), Florida Fish and Wildlife Conservation Commission, Marine Fisheries Information System, Edited Annual Landings Summary (2009 preliminary) *reef fish* fishery and consists of 73 species of mostly groupers and snappers, but also grunts, jacks, porgies, and hogfish (Ault et al. 2005a). Twenty-seven of these are specified in the commercial fishing regulations (FWC 2009). Invertebrate landings included spiny lobster, pink shrimp, and other invertebrates. Average commercial prices in 2009 were generally $2 to $3 for most grouper and snapper species, compared with $1.35 for total finfish. Average prices for invertebrates were $3.12 for spiny lobster, and $2.75 for all invertebrates excluding shrimp. Shrimp prices averaged $1.55 for all food shrimp and $1.85 for the dominant pink shrimp. These data show that fishery landings in Monroe County are valuable.

Total landings, however, have declined. Figure 5.2 uses a logarithmic scale to show rates of change. Total Monroe County landings stayed reasonably constant above 20 million pounds per year from 1986 to 1999, but since then dropped by half although some improvement occurred between 2007 and 2009. Total landings of groupers and snappers, and spiny lobsters, also declined. These trends, expressed as the change in the three-year moving

Figure 5.2: Trends in main commercial fishery landings: Monroe County



Source: FWRI (full description below Table 5.4)

average between 1986-88 and 2007-09, showed that groupers and snappers declined 37% (2.917 to 1.829 million pounds), spiny lobster declined 39% (5.355 to 3.276 million pounds) while total landings for Monroe County declined 50% (19.951 to 9.877 million pounds). Despite absolute declines in reef fisheries for snapper and grouper and spiny lobster, these fisheries were relatively successful compared to landings of all other finfish and invertebrate species which fell by 59%.

The situation is different, however, if we take pink shrimp into consideration (shown as a dotted line on Figure 5.2). The three-year moving average fell from 5.7 million pounds in 1986-88 to only 1.01 million pounds in 2007-09, or by 82%. The declining trend has been particularly fierce since 2005.

Table 5.5: Total annual commercial fishery landings in Florida

Thousand Pounds	Groupers, snappers	Other finfish	Total finfish	Spiny lobsters	Pink shrimp	Other in-vertebrates	Total landings
1986	20,587	101,183	121,770	5,031	14,037	32,807	173,644
1987	21,839	102,717	124,556	6,092	12,452	50,076	193,176
1988	18,588	99,819	118,407	6,803	9,298	46,883	181,391
1989	23,391	115,484	138,875	7,814	9,255	41,483	197,427
1990	21,701	106,033	127,734	6,019	8,422	36,571	178,746
1991	20,153	92,734	112,887	7,020	8,559	27,104	155,570
1992	19,572	93,619	113,191	5,333	8,078	37,963	164,566
1993	21,996	84,341	106,337	5,377	11,421	40,161	163,296
1994	19,408	78,450	97,858	7,087	9,721	46,975	161,641
1995	16,558	47,798	64,356	7,002	14,824	40,969	127,150
1996	14,974	38,853	53,827	7,866	19,532	60,637	141,862
1997	15,889	42,442	58,331	7,108	14,273	37,394	117,107
1998	15,133	41,592	56,725	5,831	18,548	43,640	124,744
1999	17,634	42,503	60,137	7,577	10,605	42,787	121,106
2000	17,523	36,006	53,529	5,764	9,305	37,451	106,049
2001	18,707	38,860	57,567	3,405	11,313	31,529	103,815
2002	18,172	37,832	56,005	4,483	11,697	25,177	97,362
2003	17,142	37,481	54,624	4,262	11,626	28,033	98,544
2004	17,679	35,934	53,613	4,976	12,620	39,295	110,503
2005	15,861	33,649	49,510	3,364	10,897	27,097	90,868
2006	14,103	36,828	50,931	4,773	9,992	31,598	97,294
2007	12,657	32,041	44,698	3,760	5,206	30,169	83,833
2008	14,979	34,282	49,260	3,479	7,183	24,231	84,153
2009	14,092	35,240	49,332	3,815	5,445	23,090	81,682

Source: See Table 5.4

Table 5.5 shows that the state-wide declines occurred in all five categories, but were most pronounced in finfish other than groupers and snappers which declined about two-thirds, based on three-year averages (1986-88 to 2007-09). Most of the decline, however, happened before 1996 with smaller declines thereafter. Pink shrimp landings declined by half.

Table 5.6 shows that reef fish landed in Monroe County averaged 14.3% of the total Florida reef fish landed between 1986 and 2009, slightly above the County's overall average share of 13.2%. The Monroe County had a much higher share of spiny lobster (average 89.1%).

Excluding grouper and snapper, the Monroe County share was 8.1% for finfish and 10.7% for invertebrates other than spiny lobster. This share was much lower in recent years due to the decline in pink shrimp. Monroe County averaged 28% of total Florida pink shrimp landings over the full 23 years in the statistics, but after the declines accounted for only 15% in 2009.

Table 5.6: Annual commercial fishery landings, Monroe County share of Florida

Thousand Pounds	Groupers, snappers	Other finfish	Total finfish	Spiny lobsters	Pink shrimp	Other in-vertebrates	Total landings
1986	13.0%	5.6%	6.8%	86.1%	50.1%	2.9%	11.9%
1987	14.5%	4.6%	6.4%	89.7%	53.0%	2.0%	10.9%
1988	15.6%	4.4%	6.1%	92.1%	37.3%	2.6%	10.1%
1989	14.1%	5.0%	6.6%	92.8%	34.2%	3.9%	10.7%
1990	12.9%	4.9%	6.2%	90.3%	44.2%	5.0%	10.6%
1991	14.3%	6.1%	7.6%	85.5%	38.4%	7.0%	12.7%
1992	14.7%	5.8%	7.3%	87.5%	40.5%	5.4%	11.1%
1993	15.5%	6.2%	8.1%	82.7%	33.0%	4.6%	11.4%
1994	16.9%	5.0%	7.4%	88.0%	34.2%	4.1%	11.6%
1995	16.6%	10.9%	12.4%	89.2%	34.3%	6.2%	17.2%
1996	15.7%	12.7%	13.5%	90.8%	30.6%	3.7%	16.0%
1997	17.2%	9.0%	11.2%	90.9%	21.2%	7.8%	16.2%
1998	16.0%	9.1%	10.9%	90.3%	27.4%	7.5%	15.9%
1999	14.4%	9.3%	10.8%	89.7%	18.8%	11.2%	16.6%
2000	13.3%	9.8%	11.0%	88.7%	18.4%	11.8%	16.1%
2001	11.6%	9.4%	10.1%	85.3%	25.0%	8.0%	13.6%
2002	12.3%	8.8%	10.0%	90.0%	17.0%	7.7%	13.9%
2003	12.8%	10.2%	11.0%	90.3%	19.9%	6.9%	14.3%
2004	14.2%	9.4%	11.0%	90.4%	16.7%	5.6%	13.3%
2005	13.9%	13.2%	13.4%	90.0%	18.7%	5.0%	14.4%
2006	14.3%	10.0%	11.2%	90.7%	13.0%	3.8%	12.9%
2007	12.6%	8.0%	9.3%	89.9%	13.8%	4.4%	11.4%
2008	11.9%	7.0%	8.5%	84.9%	20.7%	4.1%	11.4%
2009	15.0%	9.2%	10.8%	91.6%	15.1%	3.3%	12.8%
Average	14.3%	8.1%	9.5%	89.1%	28.2%	5.6%	13.2%

Source: See Table 5.4.

These statistics give rise to two questions. The first is whether and how the decline in commercial fish catches has affected the number of commercial fishers in the Florida Keys. The number of Saltwater Product Licenses (SPL) in Monroe County declined by 54%, from an average of 3,123 in 1990/91-1992/93, to a 1,426 average for the three years to 2008/09 (Table 5.7). The declines also apply to some main endorsements to the main SPL; for stone crabs from 1,519 in 1990/91 to 392 in 2008/09 (-74%), and for crawfish/lobsters from 1,681 to 625 (-63%). Both of these fisheries have been subject to significant effort limitation programs (http://www.myfwc.com/RULESANDREGS/SaltwaterRules_history.htm).

In contrast, the number of endorsements for restricted species (RS) declined by only 10%, from 1,301 in 1990/91 (40% of total SPLs) to 1,172 in 2008/09 (86% of total SPLs). According to the commercial fishing regulations (FWC 2009), RS endorsement is required to sell any species designated as "reef fish", many of which require a federal permit as well. The main reason for the relative stability in RS endorsements, however, is that the number of species that require an RS in order to harvest commercially has increased over the period and now includes most species (Bill Sharp, personal communication, May 2010).

Table 5.7: Number of Saltwater Product Licenses, commercial fishing

Year ended June	Monroe County	Florida State	Monroe share
1991	3,186	20,139	15.8%
1992	3,171	19,429	16.3%
1993	3,011	18,762	16.0%
1994	3,011	19,968	15.1%
1995	2,940	19,421	15.1%
1996	2,932	18,146	16.2%
1997	2,901	17,575	16.5%
1998	2,704	17,021	15.9%
1999	2,560	16,159	15.8%
2000	2,408	15,395	15.6%
2001	2,284	14,880	15.3%
2002	2,064	13,799	15.0%
2003	2,012	13,462	14.9%
2004	1,952	12,856	15.2%
2005	1,858	12,501	14.9%
2006	1,607	11,578	13.9%
2007	1,445	11,219	12.9%
2008	1,467	11,480	12.8%
2009	1,365	11,259	12.1%
Average 1991-93	3,123	19,443	16.1%
Average 2007-09	1,426	11,319	12.6%
Change	-54%	-42%	-22%

Source: FRWI, http://research.myfwc.com/features/view_article.asp?id=19224

The second question is whether commercial fisheries of spiny lobster in particular have been affected by increased competition from tourists and local recreational fishers. Table 5.8 suggests that this is probably not so. Spiny lobster fisheries in Florida (of which almost 90% is in Monroe County, as shown by Table 5.6 for commercial fisheries) have declined equally strongly for commercial and recreational fishers according to a recent FWRI presentation (Sharp 2010). While there are considerable fluctuations from year to year, the proportion of the total spiny lobster catch by recreational fishers was reasonably stable at 23-25% between the 1990s and the first decade of the 2000s, as shown by the averages at the bottom of Table 5.8.

It is more likely that juvenile populations are more affected by virus disease than in the past, and that the regional overfishing has affected recruitments – probably a combination of these factors (John Hunt, personal communication, May 2010).

Table 5.8: Spiny lobster landings, Florida				
Thousand pounds	Commercial fishers	Recreational fishers	Total landings	Recreational share of total
1993/94	5,310	1,883	7,193	26%
1994/95	7,182	1,906	9,088	21%
1995/96	7,017	1,931	8,948	22%
1996/97	7,744	1,923	9,667	20%
1997/98	7,640	2,304	9,944	23%
1998/99	5,448	1,300	6,748	19%
1999/00	7,669	2,462	10,131	24%
2000/01	5,569	1,950	7,519	26%
2001/02	3,079	1,251	4,330	29%
2002/03	4,577	1,455	6,033	24%
2003/04	4,162	1,411	5,573	25%
2004/05	5,474	na	na	na
2005/06	2,963	1,131	4,094	28%
2006/07	4,799	1,305	6,104	21%
2007/08	3,778	1,215	4,993	24%
2008/09	3,269	1,262	4,531	28%
2009/10	4,257	1,116	5,373	21%
Average per fishing season				
1993-2000	6,697	1,957	8,655	23%
2001-2009	4,040	1,268	5,308	25%

Source: Sharp (2010). Source of commercial fishing data: landings reported to the Florida Trip Information System. Recreational: from surveys of recreational lobster permit holders.

5.4 BIOPHYSICAL RESEARCH DIRECTIONS

This section contains a few representative examples rather than an encyclopedic description of the biology of the Florida Keys coral reefs. An overall perspective is given in Jaap et al. (2008), which is part of large publication describing all the reefs in the United States, including the Pacific and Caribbean. It also has a chapter on the importance of studying the paleoclimate in the Keys (Lidz et al. 2008), the "quaternary" perspective advocated by Precht and Miller (2007).

The Fish and Wildlife Research Institute (FWRI) in Marathon conducts biophysical research focused on Florida Keys issues. The FWRI takes two approaches: research into fisheries and related matters including programs focusing on lobsters and finfish, and building science relating to the ecosystem services of the Florida Keys, through surveying, monitoring, and devising conceptual models of the marine ecosystem. The latter approach delivers fisheries-dependent programs providing size and other structural data on landings.

Examples of the fisheries and related research follow, dealing with research into seagrass habitats, spiny lobsters, and the queen conch, and into strategic planning for the Florida Bay. As noted above, the aim is to provide a general rather than comprehensive impression of research undertaken by the FWRI and others that remains vitally important in the build-up of knowledge in a time threatened by rapidly changing climatic conditions.

5.4.1 SEAGRASS BEDS

The general objective of seagrass monitoring in the Sanctuary is to measure the status and trends of seagrass communities to evaluate how best to protect and restore the living marine resources. "The scope and depth of this monitoring effort are without precedent or peer for seagrass ecosystems throughout the world." (Fourqurean 2009)

Many studies in the Caribbean have documented the ecological importance of seagrass beds and mangroves as nursery areas for reef fishes of recreational and commercial importance. "Describing the relationship between seagrass habitats and fish assemblages, especially in environmentally sensitive areas such as the FKNMS, is critical for evaluating patterns and trends in the ecosystem and evaluating the recovery of impacted areas. .. Ultimately, managers must consider a suite of habitats that may be accommodating the life stages of a wide variety of fish species when making management decisions especially as they relate to .. establishment of protected areas." (Acosta et al. 2007, p 16)

5.4.2 SPINY LOBSTERS

The history of spiny lobster fishery in Florida, centered on the Keys, has been told up to the 1990s (Hunt 2000). During the 20th century, the fishery for spiny lobsters (*Panulirus argus*) evolved from small undercapitalized operations to a large, economically important, heavily capitalized fishery. The growth evoked considerable management concern and controversy, especially during the 1980s and 1990s.

This led to the Lobster Trap Certification Program, entered into the Florida Statutes in 1992. In that year, commercial fisheries covered the Gulf and Atlantic waters of the Florida Keys and along the east coast north to the Palm Beach area. The fishing effort also extended west of the Dry Tortugas, where the mean carapace length was 114.9 mm, about 30 mm more than the mean size from the rest of the fishery.

The trap certification program in 1992 established an individual transferable certificate for the use of a trap, developed a formula to set the initial allocation of certificates, and established that the management objective of the program was to reduce the total number of traps.

The primary prediction was that lobster landings would remain cyclically stable as trap numbers decreased, that the season length might increase, and the number of sublegal lobsters in traps might decrease, ameliorating any impacts of fishing practices in the absence of active measures to reduce sublegal lobster mortality. However, commercial fishers expressed concern that recreational fishers might reap most of the benefit of increased lobster availability as trap numbers declined.

Referring back to the statistics in the previous section, spiny lobster landings have declined since the 1990s, but not as much as most other catches (Table 5.5). Recreational fishers have not taken an increased share of total catches (Table 5.8).

A recent study has provided the first quantitative biogeographic description of hardbottom communities of the Florida Keys, confirming the suspected relationship between the structural features of hardbottom habitat and their value as nurseries for juvenile spiny lobster (Bertelsen et al. 2009). Hardbottom habitat constitutes a large proportion of the coastal waters of South Florida, but it is a chronically understudied feature of the marine seascape in this region.

The study estimated the relative bottom coverage of vegetation (seagrass and macroalgae) and the abundance of sponges, corals and other crevice-bearing structures, as well as the abundance of juvenile lobsters. The relationship between habitat and size-specific juvenile lobster abundance was estimated using a multivariate statistical approach. Branching-candle sponges and octocorals tended to be under-used by lobsters compared to preferred loggerhead sponges, coral heads, and solution holes which were used more frequently. As the lobsters grew, they changed their shelter preference. Small juveniles tended to occupy a variety of sponges, whereas large juveniles preferred hard structures such as coral heads and solution holes.

Like most coastal habitats, hardbottom is threatened by a variety of environmental perturbations, most of which are of human origin. Impacts on the abundance of lobster have been documented on hardbottom areas in Florida affected by siltation. Declining water quality and harmful algal blooms are the suspected culprits that have triggered massive die-offs of sponges in the Florida Keys and wholesale reconfiguration of impacted hardbottom areas. Commercial fishing removes approximately seven million sponges from shallow hardbottom habitat in the Florida Keys each year, with unknown consequences, but the indirect effects of other fishing activities may be more severe (p 309).

5.4.3 QUEEN CONCH

In Florida, the fishery for the iconic queen conch (*Strombus gigas* L.) has been closed since 1986 due to declines attributed in part to habitat degradation and overfishing. In the late 1990s, a study of tagged conchs showed a variety of habitat preferences, from having strong preferences for coarse sand and avoiding rubble, to showing no habitat preferences (Glazer and Kidney 2004).

Two separate conch populations were studied in parallel between 2004 and 2008: one near-shore, the other offshore. In the offshore situation, reproduction proceeds fairly normally, but not in the near-shore position. A number of genes have been identified that differ between conch in the near-shore and offshore zones (Glazer et al. 2008).

There may be a connection between climate change and reproductive behavior with conchs in different locations being affected differently by temperature change and light conditions, affecting their genetic setup and how this translates to population increase (Bob Glazer, personal communication, August 2009).

5.4.4 Importance of Florida Bay

Florida Bay is of particular interest for a number of reasons, including its connections to the mainland Everglades National Park as well as the Florida Keys ecosystem.

The bay includes more than 200 small islands, many of which are rimmed with mangroves. Florida Bay supports numerous protected species, and provides critical habitat for commercially important species, such as spiny lobsters, stone crabs, and many important finfish species. It also serves as the principal nursery for the offshore Tortugas pink shrimp, which supports an important fishery (Hunt and Nuttle 2007, p 1).

The report is an example of the FWRI's second approach, which relates to the ecosystem aspects of the Florida Keys. It documents the progress made towards the objectives established in the 1997 Florida Bay Strategic Plan. The inception of the Comprehensive Everglades Restoration Plan (CERP) in 2000 signals a shift in resource management away from the reactive stance of protecting natural resources, toward the proactive pursuit of restoring south Florida's ecosystems. In general, ecosystem restoration challenges us to look ahead.

The report identifies a number of issues:

- The alarming ecosystem changes occurring in the Florida Bay in the 1980s and 1990s which led to the CERP
- The main external factors that control the movement of water and solutes within Florida Bay and their exchange with the Everglades and adjacent marine systems
- External sources of nutrients and their effect on water quality
- Plankton blooms
- Seagrass ecology, since seagrasses account for a major portion of the primary production in the Florida Bay ecosystem.

5.4.5 Overfishing reef fish

Jerald Ault, James Bohnsack, Jiangang Luo and Steven Miller have often joined forces along the lines of Miller's cooperation with Mark Chiappone described in Section 5.2. Two papers in 2005 concerned overfishing, especially of members of the "snapper-grouper reef fish complex". The first FKNMS management plan in 1996 noted that the Florida Keys reef ecosystem is considered one of the nation's most significant and most stressed marine resources. There is much to lose as the Florida Keys have more than 500 fish species, including almost 400 that are reef-associated, and thousands of invertebrates, including corals, sponges, shrimps, crabs, and lobsters.

The goods and services of the ecosystem are threatened by increased exploitation and environmental changes from a rapidly growing regional human population. The reef fish in the Florida Keys are experiencing overfishing relative to established benchmarks for resource sustainability (Ault et al. 2005a).

Reef fisheries target the snapper-grouper complex. Species utilize a mosaic of cross-shelf habitats and oceanographic features over their life spans. Different snapper and grouper species use different habitats and spawning grounds, adding to the ecological complexity and exacerbating the risks of overfishing.

In the interest of future prospects for sustainable fisheries, the authors noted (p 617): “An immediate priority is to reduce fishing mortality rates in the Florida coral reef ecosystem to levels that ensure long-term fishery sustainability and productivity. Whether stocks decline from fishing or detrimental environmental changes, the appropriate fishery policy choice is the same: reduce fishing pressure.”

Using length as a measure of exploitation rates can be deceptive. The impact of exploitation is more severe for the slow-growing, long-lived groupers and hogfish than for other members of the snapper-grouper complex. In addition, exploitation rates appear to differ throughout Florida, but are most intense in the Florida Keys. Because of these factors, management to build sustainable fisheries may need to consider the entire reef-fish complex and perhaps invoke a spatial context to interventions. (Ault et al. 2005b, p 422)

6 SOCIOECONOMIC AND RELATED INDICATORS

6.1 ECONOMIC TRENDS

The United States benefits from a set of centralized statistics ranging from national to county level, compiled by the Bureau of Economic Analysis (BEA) of the Department of Commerce. Some data are compiled by other agencies, but the BEA framework provides some assurance that the information is generally internally consistent, and it is the source of the tables following. Tourism data are the subject of Section 6.2, while the physical data for commercial fisheries were shown in the previous chapter (Section 5.3).

6.1.1 POPULATION

Table 6.1 puts the surrounding demographic environment into perspective. While the total US population has grown at relatively modest rates – at 1.1% per annum between 1969 and 2008 and a similar rate (1.0%) in the more recent past from 1999 – Florida's growth was much higher over the full forty years (2.7% pa), though it has slowed down to 1.8% over the past decade. The population growth in the South Florida Metropolitan Area (Miami-Dade, Broward and Palm Beach Counties) was actually less than in the State as a whole: 2.4% pa over the long period, and slowing to only 1.2% pa between 1999 and 2008.

Table 6.1: Population trends, South Florida Metropolitan Area versus USA and total Florida

Million	USA	Florida	South Florida	FL/US	SFL/FL
1969	201.3	6.64	2.18	3.3%	32.9%
1979	224.6	9.47	3.12	4.2%	33.0%
1989	246.8	12.64	3.98	5.1%	31.5%
1999	279.0	15.76	4.93	5.6%	31.3%
2000	282.2	16.05	5.03	5.7%	31.3%
2001	285.1	16.35	5.12	5.7%	31.3%
2002	287.8	16.68	5.21	5.8%	31.3%
2003	290.3	16.98	5.28	5.8%	31.1%
2004	293.0	17.38	5.36	5.9%	30.9%
2005	295.8	17.78	5.44	6.0%	30.6%
2006	298.6	18.09	5.47	6.1%	30.2%
2007	301.6	18.28	5.47	6.1%	29.9%
2008	304.4	18.42	5.50	6.1%	29.9%
Annual change					
1969-2008	1.1%	2.7%	2.4%		
1999-2008	1.0%	1.8%	1.2%		

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

The South Florida Metropolitan Area relative to the total State population fell from 33% in the 1970s to 31.3% at the turn of the century, and was just below 30% in 2008. Meanwhile, the Combined Statistical Area of which Orlando is part (Orlando-Deltona-Daytona Beach) grew from 696,300 in 1969 to 2.7 million in 2008, increasing its share of the total population in Florida from 10.5% to 14.8% (more percentage points than South Florida lost).

Table 6.2: Monroe County population trends

Persons	Population	Annual change	Monroe /Florida	Monroe /SFL
1969	52,471		0.79%	2.40%
1979	64,586	2.1%	0.68%	2.07%
1989	77,058	1.8%	0.61%	1.93%
1990	78,239	1.5%	0.60%	1.92%
1991	78,991	1.0%	0.59%	1.89%
1992	79,676	0.9%	0.58%	1.87%
1993	82,182	3.1%	0.59%	1.89%
1994	81,594	-0.7%	0.57%	1.84%
1995	81,461	-0.2%	0.56%	1.79%
1996	81,358	-0.1%	0.55%	1.75%
1997	80,925	-0.5%	0.53%	1.70%
1998	80,840	-0.1%	0.52%	1.67%
1999	79,973	-1.1%	0.51%	1.62%
2000	79,483	-0.6%	0.50%	1.58%
2001	79,105	-0.5%	0.48%	1.54%
2002	78,963	-0.2%	0.47%	1.51%
2003	78,880	-0.1%	0.46%	1.49%
2004	77,901	-1.2%	0.45%	1.45%
2005	76,135	-2.3%	0.43%	1.40%
2006	74,104	-2.7%	0.41%	1.36%
2007	73,420	-0.9%	0.40%	1.34%
2008	73,298	-0.2%	0.40%	1.33%

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

Though Miami and the other parts of the South Florida Metropolitan Area have been losing share of the total population in the State, 5.5 million is still a formidable presence for tiny Monroe County to have just north of its border (Table 6.2). While its population increased quite significantly (1.9% pa) between 1969 and 1993, when its reached its peak of more than 82,000 residents, the County still lost share of both the total Floridian population and the South Florida Metropolitan Area during that period.

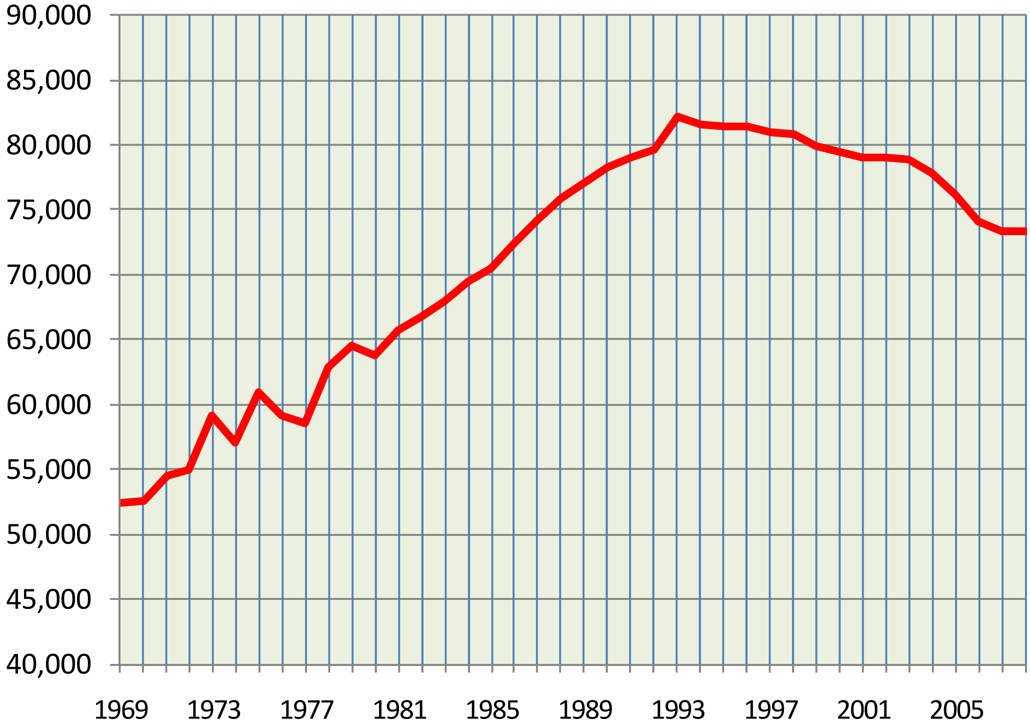
Since 1993, this trend has intensified, as population numbers in Monroe County began moving backwards every year, especially since 2003 and 2004.

The interruption to the historical growth, while understandable in terms of environmental stress and associated carrying capacity, is nevertheless remarkable (Figure 6.1). The growth phase over at least 24 years covering the period for which the BEA has posted data on the Internet was quite steady, projecting the total population from 52,400 in 1969 to 82,200 in 1993. The average rate of decline over the 15 years to 2008 was 0.8%, though not as steady as the preceding growth phase. It has taken the ratio of Monroe County's population to the population of Miami-Dade, Broward and Palm Beach Counties to a new low of 1.33%, from 2.4% in 1969 through 1.9% when Monroe's population peaked in 1993.

6.1.2 Economic growth

The macroeconomic environment provided by the total United States and Florida is expressed by the GDP and the Gross State Product (GSP), respectively. The statistics in Table 6.3 do not include the recession year of 2009, but even before then Florida suffered negative growth – a marginal decline in real terms in 2007 and a further 1.6% loss in 2008. The US economy slowed to 0.7% growth in 2008, in constant values.

Figure 6.1: Monroe County population, 1969-2008



Source: BEA Regional Economic Accounts

Despite the decline in 2007 and 2008, the level of real GSP in 2008 relative to 1997 implied an annual growth rate for Florida of 3.5%, compared with 2.7% pa for the United States. Until fairly recently, the performance of the fourth-largest State to which the Florida Keys are literally an appendage has, for better or worse, been one of positive growth. This is so at

Table 6.3: GDP United States and Gross State Product Florida

$billion	United States			Florida		
	Current prices	2000 dollars*	Deflator	Current prices	2000 dollars*	Deflator
1997	8,238	8,621	95.6	391	415	94.4
1998	8,680	9,005	96.4	417	436	95.8
1999	9,201	9,404	97.8	443	453	97.6
2000	9,749	9,749	100.0	471	471	100.0
2001	10,058	9,837	102.3	497	485	102.6
2002	10,398	9,982	104.2	523	497	105.1
2003	10,886	10,226	106.5	559	520	107.4
2004	11,607	10,580	109.7	607	549	110.7
2005	12,339	10,912	113.1	670	589	113.7
2006	13,091	11,219	116.7	721	614	117.6
2007	13,716	11,439	119.9	742	613	121.0
2008	14,166	11,524	122.9	744	603	123.3

* Billions of chained dollars at 2000 values.

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

least according to the conventional economic growth data, which make no allowance for the real cost of ecosystem services.

Table 6.4: Gross State Product and Personal Income

$ billion	GSP	Personal income		
	Florida	Florida	Monroe	Monroe/FL
1990	329.5			
1991	330.6			
1992	341.5			
1993	353.2			
1994	367.4			
1995	379.9			
1996	398.6			
1997	414.7	400.9	2.61	0.65%
1998	435.6	427.8	2.83	0.66%
1999	453.3	441.1	2.81	0.64%
2000	471.3	466.6	3.02	0.65%
2001	484.9	475.2	2.93	0.62%
2002	497.3	483.7	2.88	0.59%
2003	520.4	494.5	2.92	0.59%
2004	548.6	526.4	3.19	0.61%
2005	589.3	557.0	3.40	0.61%
2006	613.6	587.1	3.65	0.62%
2007	613.4	589.9	3.73	0.63%
2008	603.5	583.7	3.68	0.63%

Note: Small discrepancy in 1990 GSP (going from SIC to NAICS basis) used to adjust previous SIC statistics. - Personal income correlated with GSP since 1997 but previously higher, and suggesting unrealistically low growth rate for Florida. Monroe personal income series probably correlated with GSP from 1997, via total state personal income.

Source: BEA Regional Economic Accounts, at constant 2000 price dollars (http://www.bea.gov/regional/).

Estimates of economy-wide GDP and GSP statistics do not go as far as to county level, but personal income statistics do, though they appear to be compatible only since about 1997 (Table 6.4). Comparing 2008 with 1990 shows an average annual increase of 3.4% for Florida and almost the same rate for 1997-2008 (3.5% pa), during which period the personal income in Monroe County increased by 3.2% pa.

This differs from the population statistics in Table 6.2 which show continued falls from 1993. The difference is probably attributable to influx of wealthy people, as discussed in the scenario-planning workshops in 2008 (Appendix 2). Other statistical evidence shows that structural change is happening (see below).

6.1.3 Employment patterns

Total employment increased in Florida from an average of less than 2.9 million between 1969 and 1973, to 7.8 million in 1994-98 and 10.4 million in 2008 (Table 6.5). This is equivalent to an annual rate of 4.1% in the first period to 1994-98 and 2.6% between 1994 and 2008. The equivalent figures for Monroe County were 2.8% and 1.6% per annum, respectively. The increase continued despite the population decline in the County.

Table 6.5: Total employment, Florida and Monroe County			
Thousand persons	**Florida**	**Monroe**	**Monroe/FL**
Average 1969-73	2,857	24.7	0.9%
Average 1974-78	3,868	28.4	0.7%
Average 1979-83	4,826	34.5	0.7%
Average 1984-88	5,955	40.0	0.7%
Average 1989-93	6,764	44.0	0.7%
Average 1994-98	7,754	49.0	0.6%
1994	7,234	46.1	0.6%
1995	7,494	47.5	0.6%
1996	7,740	48.7	0.6%
1997	8,005	50.5	0.6%
1998	8,298	52.2	0.6%
1999	8,567	51.9	0.6%
2000	8,842	53.1	0.6%
2001	8,917	53.8	0.6%
2002	9,056	53.8	0.6%
2003	9,286	55.1	0.6%
2004	9,662	55.0	0.6%
2005	10,088	55.5	0.6%
2006	10,407	56.0	0.5%
2007	10,553	56.3	0.5%
2008	10,424	57.9	0.6%

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

The high employment level in Monroe County is striking. In 2008, 57,900 persons were recorded as working there, while the total population had declined to 73,300. The ratio of employment to population was 79%, compared with 56.5% in total Florida, which is a more normal" workforce ratio. The reason is the number of Hispanic and other people who work in Monroe County in the hospitality and retail industries in particular, but live elsewhere.

Table 6.6 shows that accommodation and food services, and retail trade, are indeed the main industries in the Keys (which have little manufacturing industry and no agriculture). The hospitality industry accounted for 10,600 of the total 58,000 persons working in the Keys in 2008 – though the number has declined from 11,600 since 2001. Retail trade employed 6,500, again a decline, from 6,900 in 2001.

The third-most important industry is real estate, which in contrast to the two top employing industries has been growing strongly, from 3,000 in 2001 to 5,000 in 2008. This may be associated with the structural change to which many participants in the scenario-planning workshops in 2008 referred. Younger people and others are moving out, and absentee landlords are moving in, buying residential properties which they occupy at most on a part-time basis.

Table 6.6: Employment by industry in Monroe County, 2001-2008, compared with Florida

Employment category, persons	2001	2002	2003	2004	2005	2006	2007	2008
Private employment	46,180	46,058	47,195	47,125	47,727	48,248	48,577	50,187
of which								
Accommodation and food services	11,644	10,964	11,325	11,434	10,737	10,000	9,894	10,617
Retail trade	6,932	6,823	6,694	6,646	6,659	6,782	6,642	6,496
Real estate, rental and leasing	2,994	3,170	3,630	4,103	4,639	4,797	4,525	5,024
All other private employment	21,570	20,957	21,649	22,183	22,035	21,579	21,061	22,137
Government and government enterprises	7,668	7,753	7,868	7,871	7,766	7,733	7,772	7,741
of which								
Federal civilian	1,252	1,278	1,331	1,263	1,193	1,130	1,137	1,183
Military	1,555	1,675	1,724	1,730	1,697	1,686	1,670	1,647
State	763	741	747	750	721	684	678	666
Local	4,098	4,059	4,066	4,128	4,155	4,233	4,287	4,245
Total private and government employment	53,848	53,811	55,063	54,996	55,493	55,981	56,349	57,928
Relative to total employment	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Private employment	85.8%	85.6%	85.7%	85.7%	86.0%	86.2%	86.2%	86.6%
of which								
Accommodation and food services	21.6%	20.4%	20.6%	20.8%	19.3%	17.9%	17.6%	18.3%
Retail trade	12.9%	12.7%	12.2%	12.1%	12.0%	12.1%	11.8%	11.2%
Real estate, rental and leasing	5.6%	5.9%	6.6%	7.5%	8.4%	8.6%	8.0%	8.7%
All other private employment	40.1%	38.9%	39.3%	40.3%	39.7%	38.5%	37.4%	38.2%
Government and government enterprises	14.2%	14.4%	14.3%	14.3%	14.0%	13.8%	13.8%	13.4%
of which								
Federal civilian	2.3%	2.4%	2.4%	2.3%	2.1%	2.0%	2.0%	2.0%
Military	2.9%	3.1%	3.1%	3.1%	3.1%	3.0%	3.0%	2.8%
State	1.4%	1.4%	1.4%	1.4%	1.3%	1.2%	1.2%	1.1%
Local	7.6%	7.5%	7.4%	7.5%	7.5%	7.6%	7.6%	7.3%
Total private and government employment	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Distribution in total Florida	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Private employment	86.5%	86.6%	86.7%	87.1%	87.5%	87.7%	87.7%	87.6%
of which								
Accommodation and food services	7.4%	7.5%	7.5%	7.6%	7.6%	7.6%	7.6%	7.7%
Retail trade	12.1%	11.9%	11.6%	11.5%	11.4%	11.3%	11.3%	11.1%
Real estate, rental and leasing	3.9%	4.1%	4.3%	4.7%	5.2%	5.5%	5.4%	5.8%
All other private employment	63.1%	63.1%	63.2%	63.3%	63.4%	63.4%	63.5%	63.0%
Government and government enterprises	12.5%	12.4%	12.3%	12.0%	11.7%	11.5%	11.5%	11.6%
of which								
Federal civilian	1.3%	1.3%	1.4%	1.3%	1.3%	1.2%	1.2%	1.2%
Military	1.2%	1.2%	1.2%	1.1%	1.0%	1.0%	1.0%	1.0%
State	2.5%	2.3%	2.2%	2.2%	2.1%	2.0%	1.9%	1.9%
Local	7.5%	7.6%	7.6%	7.5%	7.3%	7.3%	7.3%	7.4%
Total private and government employment	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: BEA Regional Economic Accounts (http://www.bea.gov/regional/)

Private employment accounted for about 86% of total employment in Monroe County between 2001 and 2008. Employment by government and government enterprises remained fairly constant numerically, with civilian federal institutions declining and being outnumbered by the military in their Key West establishments. The largest employment group was local government with over 4,200 employees in 2008. State government employment in Monroe County was relatively small, and declining.

The bottom panel of Table 6.6 provides a basis for comparing the employment pattern in Monroe County with total Florida. It is strikingly different for accommodation and food services (18.3% of employees in Monroe County, 7.7% in Florida). Retail trade held similar shares in Florida and the Keys, and real estate, while increasing its share both statewide and in Monroe County, by 2008 had grown to account for 8.7% of all employment in the County compared with 5.8% in total Florida.

Federal employment, in particular the military, was a relatively stronger presence in Monroe County than in Florida as a whole. State employees were relatively low in numbers in Monroe County (the seat of government is elsewhere), while the representation of local government employees was on a par with the State average.

6.2 Tourism

The Key West Chamber of Commerce publishes a monthly set a statistical indicators that give a picture of tourism and recreation activities, though some of these indicators have to be treated with caution as discussed below. The ultimate sources from which the Chamber compiles the data include Monroe County, the Key West Port Authority, the Key West International Airport, and the Florida Department of Revenue.

Table 6.7: Monroe County Bed Tax, Key West

$ '000	At current prices	CPI deflator	At constant 2000 prices	Change on last year
1995	4,392	152.4	6,182	
1996	4,893	156.9	6,689	8.2%
1997	5,341	160.5	7,138	6.7%
1998	5,352	163.0	7,043	-1.3%
1999	5,858	166.6	7,543	7.1%
2000	6,228	172.2	7,758	2.9%
2001	6,425	177.1	7,782	0.3%
2002	6,420	179.9	7,654	-1.6%
2003	6,850	184.0	7,986	4.3%
2004	7,271	188.9	8,257	3.4%
2005	7,220	195.3	7,930	-4.0%
2006	7,421	201.6	7,896	-0.4%
2007	7,893	207.3	8,167	3.4%
2008	8,166	215.3	8,135	-0.4%
2009	8,023	214.5	8,023	-1.4%

Fourpenny tax from June 2009 converted to previous basis.

Source: As compiled by Key West Chamber of Commerce

Monroe County in 1991 introduced a 3% bed tax (called a threepenny tax) to generate revenue from tourist expenditure at hotels, motels and other short-term lodging while having as little impact as possible on residents. The bed tax was increased to 4% from June 1, 2009, but the statistics in Table 6.7 have been adjusted back to a 3% base to provide a consistent time series.

Expressed in constant prices, using the implicit deflator from Florida's GSP calculations, revenue from the bed tax generally increased up to 2004, but has fluctuated around a static trend since then. The value of bed tax as a tourism indicator, however, is limited by factors such as the exclusion of day visitors (including a growing number of cruise ship passengers) and visitors staying with family and friends, categories that have both increased strongly since the 1990s. There has also been a strong move toward greater condominium/time share ownership among visitors, and many stay in government-owned accommodations that are not taxed or may not have been taxed throughout the whole period. Finally, compliance with the bed tax itself may have improved over the years, which could be a significant factor.

The statistics in Table 6.7 cover Key West (Monroe County District 1), which accounted for about 54% of total bed tax collections in the County between FY 2002 and 2009. It increased in FY 2009 and continued the increase in the first half of FY 2010, according to the Monroe County *Four Penny Revenue Report*. This report also shows Key West's 54% share applying through the 1990s, so the Key West bed tax trend was until recently largely representative of Monroe County as a whole for visitors staying overnight in paid accommodation, subject to the qualifications listed in the previous paragraph.

Compared with the 54%+ of total bed tax receipts from Key West, District 2 (Lower Keys) represents less than 6%, Districts 3 and 5 (Marathon and Key Largo) about 14% each, and

Table 6.8: Monroe County Bed Tax, by districts

$thousand at average FY 2009 prices

Fiscal year	Key West	Lower Keys	Marathon	Islamorada	Key Largo	County
2002	7,495	772	1,897	1,802	1,997	13,962
2003	7,837	778	2,040	1,876	2,054	14,584
2004	8,267	868	2,082	1,968	2,134	15,320
2005	8,305	879	2,112	2,045	2,208	15,549
2006	7,669	872	2,159	1,995	1,998	14,693
2007	7,961	922	2,250	2,094	2,195	15,421
2008	8,221	848	1,901	1,911	2,108	14,989
2009	7,899	748	1,934	1,302	1,833	13,716

Proportion of Monroe County

Fiscal year	Key West	Lower Keys	Marathon	Islamorada	Key Largo	County
2002	53.7%	5.5%	13.6%	12.9%	14.3%	100%
2003	53.7%	5.3%	14.0%	12.9%	14.1%	100%
2004	54.0%	5.7%	13.6%	12.8%	13.9%	100%
2005	53.4%	5.7%	13.6%	13.2%	14.2%	100%
2006	52.2%	5.9%	14.7%	13.6%	13.6%	100%
2007	51.6%	6.0%	14.6%	13.6%	14.2%	100%
2008	54.8%	5.7%	12.7%	12.7%	14.1%	100%
2009	57.6%	5.5%	14.1%	9.5%	13.4%	100%
Average	53.9%	5.7%	13.9%	12.6%	14.0%	100%

Adjustment made for increased bed tax June-September 2009 (4/3).

Source: Monroe County Tourist Development Council, from Monroe County tax records (updated statistics from 2005 directly from Monroe County *Fourpenny Revenue Report).* Deflated by Bureau of Labor Statistics Consumer Price Index for all urban consumers.

District 4 (Islamorada) about 13%. There is no immediate explanation why District 4 showed a 32% decline in FY 2009 (after adjusting for the increased bed tax rate), compared with falls of 4% in Key West, 12% in Lower Keys, and 13% in Key Largo, and a rise of 2% in Marathon.

Adjusted back to a 3% tax but unadjusted for inflation, four of the five districts showed increases in the first half of FY 2010: Key West by 9%, Lower Keys 3%, Marathon 5%, and Islamorada 7%. There was a 2% decline in Key Largo, while the total adjusted bed tax for the County rose by 6%. The consumer price index rose by 1.9% in the first six months of 2010 compared with the corresponding period of 2009, suggesting that tourism, if measured by the adjusted bed tax, may be turning the corner, with Key West continuing to increase its lead but at least some recovery showing in District 4, Islamorada.

Table 6.9: Taxable sales, Monroe County, 2003-2009

$million at 2000 values	Tourism & recreation	Other retail sales	Total retail sales	Commercial sales	Grand total taxable sales	*Tourism & re-creation share*
2003	908.7	856.4	1,765.0	261.8	2,026.8	*44.8%*
2004	980.8	803.4	1,784.1	327.8	2,111.9	*46.4%*
2005	977.5	859.8	1,837.3	342.4	2,179.7	*44.8%*
2006	966.4	842.0	1,808.3	388.3	2,196.7	*44.0%*
2007	971.0	787.3	1,758.3	359.6	2,117.9	*45.8%*
2008	935.4	709.6	1,645.0	325.9	1,971.0	*47.5%*
2009	878.2	651.6	1,529.8	291.2	1,821.0	*48.2%*

Note: As discussed in the text, these statistics underestimate the true contribution of tourism and recreation by an estimated 25-30% above the 44-48% contribution shown in the right-hand column.

Source: As compiled by the Key West Chamber of Commerce, adjusted by implicit deflator for Florida Gross Product (2009 using closely correlated US implicit deflator).

Taxable sales data represent an attempt to identify tourism and recreation sales separately from other retail sales, and from commercial sales (Table 6.9). Between 2003 and 2009, these sales increased in 2004, remained roughly constant up to 2007 and then declined in 2008 and again in 2009. Other retail sales generally declined. The share of tourism and recreation in total taxable sales was about 44-46% between 2003 and 2007 before increasing to 48% in 2008 and 2009. This in itself marks Monroe County as a highly tourism-dependent economy, but the true contribution of tourism and recreation to the local economy is underestimated. Many other retail and commercial sales would satisfy demand by residents dependent on the tourist trade, and some represent direct sales to visitors.

Based on NOAA's authoritative visitor and resident surveys in 1995-96 and 2007-08 (reported in Table 6.26 in Section 6.4), visitor spending accounts for 60% of gross sales in Monroe County, compared with the 44-48% shown in Table 6.9.

The analysis of seasonality in Section 6.2.1 below draws attention to one of these issues, suggesting that visitors may self-cater, purchasing from local supermarkets and cooking for themselves in their resort or motel. Furthermore, analysis reported in Section 6.4.4 shows a strong increase in the number of persons owning condominiums and time-share facilities (Table 6.26). They would also self-cater to a large extent during their visits.

Other factors weaken the connection between the statistics in Table 6.9 and the true situation. For example, most but not all hotel, motel, and restaurant usage is related to tourism and recreation. The most reliable way of defining the true contribution of tourism and recreation to the Monroe County economy has been through the detailed surveys of tourists and residents in 1995-96 and 2007-08 (Section 6.4). The published regular economic indicators are just not adequate. This probably applies to other locations as well.

Table 6.10: Passenger arrivals, Key West Airport

Thousand	Arrivals	Change
1996	271.7	
1997	267.7	-1.5%
1998	257.6	-3.8%
1999	268.9	4.4%
2000	275.4	2.4%
2001	255.9	-7.1%
2002	259.3	1.4%
2003	286.8	10.6%
2004	291.5	1.6%
2005	313.9	7.7%
2006	276.2	-12.0%
2007	263.8	-4.5%
2008	222.2	-15.8%
2009	229.3	3.2%

Source: As compiled by Key West Chamber of Commerce

The Key West Chamber of Commerce also compiles data on passenger arrivals at Key West International Airport (Table 6.10), which represent one of the three main modes of getting to the Keys. The others are cruise ships arriving in Key West (see below) and motoring from the north (covered by survey only).

Passenger arrivals at Key West Airport since 1996 generally stagnated until 2002 before rising to a peak of 314,000 in 2005, from which they declined to 264,000 by 2007 before plunging to below 230,000 in 2008 and 2009, presumably at least partly due to the financial crisis.

Table 6.11: Key West cruise ship data

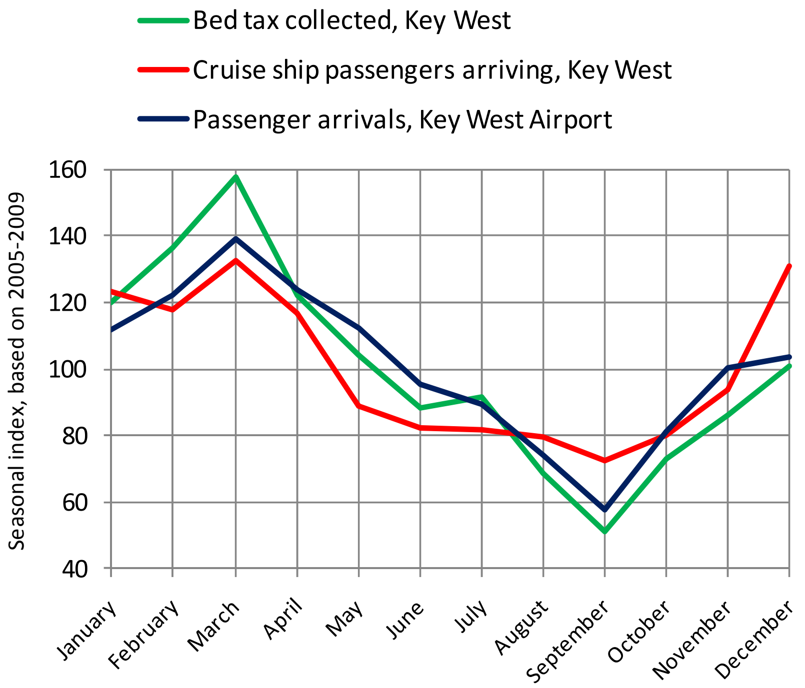
	Thousand passengers	Number of port calls	Passengers per port call
1997	588.8	340	1,732
1998	579.5	404	1,434
1999	630.7	411	1,534
2000	656.9	406	1,618
2001	679.0	362	1,876
2002	1,030.5	520	1,982
2003	1,067.2	505	2,113
2004	934.1	462	2,022
2005	925.8	461	2,008
2006	888.2	425	2,090
2007	816.9	398	2,053
2008	739.2	343	2,155
2009	859.4	369	2,329

Source: As compiled by Key West Chamber of Commerce

Cruise ships are big business in Key West and driven by different forces from other tourism in the Keys. In each peak year of 2002 and 2003 (Table 6.11), these vessels made more than 500 port calls, delivering more than a million passengers. The pace has diminished but 859,000 passengers still arrived in 2009, from 369 port calls. There has been a rising trend in the number of passengers per port call, from an average of 1,434 in 1998 to 2,329 in 2009, indicating that cruise ships are getting bigger.

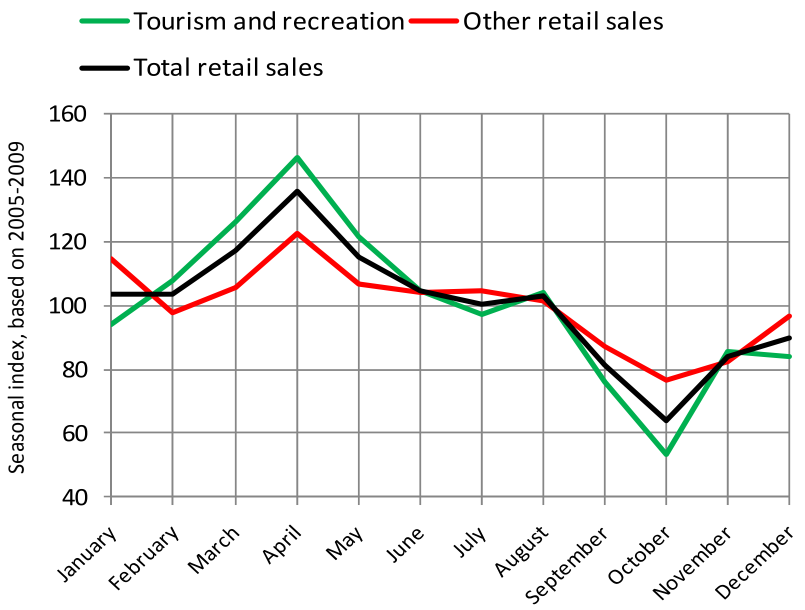
A more recent mode of transport to the Florida Keys is by catamaran ferry from Marco Island and Fort Myers Beach on the Gulf side of southern Florida. The Key West Chamber of

Figure 6.2: Seasonality of tourism indicators



Source: Monthly statistics, Key West Chamber of Commerce

Figure 6.3: Seasonality of taxable retail sales, Monroe County



Source: Monthly statistics, Key West Chamber of Commerce

Commerce compilations show 68,500 passengers were ferried to Key West in 2005, rising to 88,600 in 2006 and 99,100 in 2007, before declining in 2008 (to 80,000) and 2009 (74,800).

6.2.1 SEASONALITY

Being so dependent on tourism, the Florida Keys are subject to marked seasonal fluctuations in demand. Figure 6.2 shows that bed tax collections, passenger arrivals at Key West Airport, and cruise ship passengers visiting Key West all peak in March and decline to a trough in September.

The seasonal indices used here are based on simple averages, unadjusted for upward or downward trends in the data. However, the annual average of the three indices on Figure 6.2 happens to be exactly 100, which suggests the bias is modest. In the summer season from June to November the average is 80, and in the winter season from December to May 120. In other words, the volume of tourism according to these three series is 50% higher in the winter than in the summer season.

The patterns are reflected with a month's delay in taxable tourism and recreation-related sales (Figure 6.3). The delay must be due to reporting lags, as the March peak and September trough in tourist activity are well established. Figure 6.3 also shows that while tourism and recreation-related sales have the more pronounced seasonal pattern, other retail sales retain some of the pattern, though with less amplitude. There may be a relationship between purchases by tourists and residents across the season. More likely, the boundary is blurred between tourism and recreation-related sales and other retail sales, which are not supposed to represent tourist spending – but what happens when visitors, or relatives they stay with, go to the supermarket for their cooking and other requirements?

6.3 SOCIOECONOMIC RESEARCH PROJECTS

There has been a considerable amount of research into the socioeconomic and biophysical links in the Florida Keys, all generally classifiable under the heading of human dimensions. This section deals with research projects done elsewhere, followed by NOAA's visitor and resident surveys in Section 6.4. The problems of measuring the market and nonmarket values of the Florida Keys ecosystem are discussed in Section 6.5.

6.3.1 THE SEFCRI REPORT

Manoj Shivlani of the University of Miami's Rosenstiel School of Atmospheric and Marine Science is a leading researcher into the human use of Southeast Florida's coral reefs. A major report (Shivlani and Villanueva 2007) relates to the region covered by the Southeast Florida Coral Reef Initiative (SEFCRI), that is, the three counties covering the South Florida Metropolitan Area, plus Martin County to the north. The SEFCRI website provides the following explanation why it did not extend to Monroe County:

"[The SEFCRI] Team first gathered in May 2003 to develop local action strategies targeting coral reefs and associated reef resources from Miami-Dade, Broward, Palm Beach and Martin counties to improve the coordination of technical and financial support for the conservation and management of coral reefs. SEFCRI is targeting this region because the coral habitats are close to shore and co-exist with intensely urbanized areas that lack a coordinated management plan (like that of the Florida Keys National Marine Sanctuary)." (http://www.dep.state.fl.us/coastal/programs/coral/sefcri.htm)

Despite the exclusion of the Florida Keys, Manoj Shivlani's and Maria Villanueva's SEFCRI research provides general pointers for the Keys, though naturally there are some differences. The research is given further perspective by a presentation Shivlani gave to the Florida Reef Resilience Program (FRRP) conference reported in Section 4.2.5 (Shivlani 2008). The human dimensions of coral reef management are vitally important, he began. They include the ways individuals, groups and society interact with, affect, and are affected by the natural environment and environmental change. Relevant dimensions include:

- Half a billion people worldwide rely on coral reefs for food and income
- In the Florida Keys, commercial fisheries are closely tied to spiny lobster, reef finfish, and other species that spend part or all their life on coral reefs
- Recreational use is "over and on reefs, not always sustainably"
- In Southeast Florida, recreational users spent $2.9 billion on coral reef ecosystem-based activities in 2001
- Reefs serve essential coastline functions for humans, by providing storm damage protection and preventing coastal erosion.

Taken together, human dimensions of reef management refer to:

- Linkages between uses, valuation and perceptions of coral reef ecosystems and the resilience of coral reefs
- Relationships between the management strategies undertaken to protect coral reefs and attributes people value in coral reef ecosystems
- Responses within uses and valuation to changes in coral reefs over time
- Integration of the human and biophysical dimensions of coral reef management.

Shivlani (2008) offered the following working definition of the human dimensions of coral reef ecosystem management: "An inquiry of the linkages between the human and biophysical dimensions of reef resilience, of management strategies employed to address coral reef health, and of individuals and groups who depend on and recreate in coral reef ecosystems."

The 200-page report (Shivlani and Villanueva 2007) compares six studies carried out for SEFCRI, based on field interviews, mail-back questionnaires and Internet surveys. The stakeholder groups were charter fishing operators, commercial fishers, dive operators, recreational anglers, researchers and managers, and surfers. Apart from surfers, these groups are also prominent in the Florida Keys, which might have benefited instead from the inclusion of cruise ships visiting Key West.

There is also a larger proportion of resident people compared with tourists than would be the case in the Keys, though the report comments in connection with one of the stakeholder groups on p 104: "The visitor base has grown considerably in the few decades since the advent of SCUBA, and diving and snorkeling activities have emerged as an important (and integrated) component of the coastal tourism economy."

The people surveyed had generally long experiences using the SEFCRI region (averaging 11-15 years or more), which increases the confidence that can be attached to their attitudes (as well as indicating that they were mainly residents rather than tourists). Most charter fishing operators, dive operators, and recreational anglers rated proximity to home or port as the main factor in choosing a particular area, and did not go far from home. Commercial fishers were the only group that rated "right conditions" above proximity, which is not surprising.

Some stakeholder groups were in conflict with others: recreational boaters conflicted with dive operators and surfers, commercial fishers with recreational anglers, and anglers with dive operators.

Conditions in most stakeholders' opinion had deteriorated, *worst* for coral reefs, moderately for water quality, fisheries and use conflicts, and least for artificial reefs.

There was general disaffection with management in the SEFCRI area which lacks a coordinated management plan (based on the evidence reported in Section 6.3.2 below, the Florida Keys would have done better on this score). Of a range of management options, education was the preferred or second preferred tool in all groups. Zoning and marine protected areas were not in favor among extractive user groups (charter and commercial fishers), but were preferred by dive operators, surfers, and researchers and managers. All groups were generally dissatisfied with current management, and with the option of having less management.

The worst direct impacts by users were perceived to be by sporting divers, and commercial and recreational fishers. Land-based pollution was seen as the worst indirect impact on the reefs, and global warming as the least important. "This was most likely due to respondents either not fully understanding the effects of climate change on the region (as exhibited by the high numbers of non-responses to this question) or not accepting global warming as a local impact." (Shivlani and Villanueva 2007, pp 8-9)

In conclusion, the condition of the reef resources is generally deteriorating according to users, with coral reefs (especially), fisheries and water quality all in decline, and use conflicts rising due to larger user numbers. The majority of users considered management in the SEFCRI region to be ineffective. "While there is less consensus on specific use conflicts and the relative impacts of stakeholder groups on coral reefs, the results nevertheless reveal a base of concerned users who have witnessed a pervasive decline in their local resources and who are willing to support changes in management direction to rectify current resource conditions." (p 9)

6.3.2 Knowledge and perceptions of FKNMS strategies and regulations

Between 2004-05 and 2007, replication studies were carried out of commercial fishers, dive operators, and members of environmental groups in the Florida Keys, all originally subjected to a baseline study in 1995-96 (Shivlani et al. 2008).

Between the survey dates in 1995-96 and 2004-05, the number of Saltwater Product License (SPL) holders in Monroe County declined strongly, as shown by Table 5.7 in the previous chapter. The fall is attributed to fishery management regulations due to overfishing and excess capacity, increased land values and competition with the tourist industry for waterfront access, and higher operating costs. Because the main loss of personnel was among younger people, the remaining fisheries workforce is more professional with older, more experienced fishers, fewer part-time fishermen, more highly capitalized (more boats, equipment and gear, primarily traps), more dependent on fishing for their personal income, and more affiliated with group organizations to represent their interests.

In 1996, there were 75 dive operators in Monroe County. This increased to 89 in 2006, but some operators in 1996 had closed and new ones had opened, so only 30 of the 69 dive operators surveyed in 2006 had also been surveyed in 1996. Consequently the make-up of the dive operators has changed somewhat over the 10-year period, which (as for the fishers) may explain some of the changes in attitudes and perceptions found in the study.

Only two local environmental groups were included in both years: Last Stand and Reef Relief (the latter has since spread geographically beyond the Keys). The third original group, the Sanctuary Friends of the Florida Keys, had not been in existence for a few years in 2007; a more recently formed group called the Sanctuary Friends Foundation of the Florida Keys chose not to participate (Shivlani et al. 2008, p 108).

As well as the new Friends group, other influential local environmental groups were not included, such as Green Living and Energy Education (GLEE), which was founded in 2003. It is unclear why environmental groups had to be represented in both surveys since this criterion evidently didn't apply to dive operators, of whom most of those interviewed in 2006 were not surveyed in 1996. With all respect to the environmental groups that were represented, the study does not reflect that local environmental groups have in all probability gained considerable influence since the 1990s.

Apart from the above structural information on commercial fishers, dive operators, and environmental groups, the replication study is obviously useful for the detail it supplies for the FKNMS Socioeconomic Research and Monitoring Program. Key findings for each of the three stakeholder groups included (Shivlani et al. 2008, p ii):

All three groups

- Stakeholder attitudes, perceptions and beliefs about FKNMS outcomes and support for the FKNMS have converged.
- Either a majority or plurality of all three user groups believes that the FKNMS has benefited both the environment and economy of the Florida Keys.
- None of the user groups believe that the FKNMS zones have been effective in restoring coral reefs in the Florida Keys to what they used to be, but they understand that the conditions of the reefs are driven by many factors outside the control of the FKNMS.
- Either a majority or plurality of each of the three user groups support the FKNMS zones as currently established, except commercial fishers for the Ecological Reserves (ERs).
- Across all three user groups, only two of eight items assessed were rated as having improved in condition since the establishment of the FKNMS ("mooring buoys" and

"vessel groundings"). The avoidance of vessel groundings was one of the main motivations for creating the FKNMS.

- The items that were not rated as having improved were "water quality", "land-based pollution/sewage", "sea-based pollution/marine debris", "coral reefs", "seagrasses", and "fisheries". However, no resource condition was rated as having gotten worse by any of the three user groups since the establishment of the FKNMS. Most items received scores in the neutral or no change range.

Commercial fishing community

- There was greater support for FKNMS across a variety of aspects, with a shift from a highly negative position to majority/plurality support.
- There has been a significant shift by commercial fishers over the 10-year period towards support for the FKNMS zones; however, a plurality still does not support the ERs.
- An overwhelming majority of commercial fishers is against any more FKNMS zones of any type.

Dive operators

- There has been increased use of the FKNMS zones by dive operators, especially the Sanctuary Preservation Areas (SPAs).
- A majority or plurality of dive operators support more FKNMS zones of all types.
- A majority of dive operators believes that the SPAs have reduced conflicts between user groups. This was a significant change from expectations in the baseline study.

Local environmental groups

- Based on the study, there is a need for greater outreach and education efforts to members.
- As for dive operators but not commercial fishers, members of environmental groups support more FKNMS zones of all types.

6.3.3 The UMASS Amherst studies

Three parallel studies of recreational fishers, snorkelers, and SCUBA divers were carried out in 2006-07 for the Florida Reef Resilience Program (FRRP) by the Human Dimensions of Marine and Coastal Ecosystems Program of the University of Massachusetts Amherst (Loomis et al. 2008a,b,c). The frame of reference was related to coral reef resilience as follows (pp vii-viii):

- **Resilience:** The ability of systems to absorb disturbances, to resist phase shifts, and to regenerate and reorganize in order to maintain key functions and processes in a time span relevant to resource use and management
- **Human dimensions of coral reef management:** An area of investigation which attempts to describe, predict, understand and affect human thought and action toward coral reefs and their associated environments

- **Human dimensions of reef resilience:** The scientific investigation of the linkages between reef resilience, the management strategies employed to improve the health of coral reefs, and individuals and groups who depend on and enjoy coral reef environments.

These surveys provide valuable pointers to the future through comprehensive profiles of the three user groups (resident and non-resident anglers, snorkelers, and divers), including the length of their experience which proved a powerful variable in the South Florida SEFCRI report (Shivlani and Villanueva 2007). Three tables showing specific results from the three user groups show the scope of this research.

Asked about the impact on the ecological health of coral reefs in the Florida Keys (Table 6.12), residents rated climate change worst, ahead of hurricanes and commercial fishing. Impact from water quality was next, and scuba diving and snorkeling would have the least impact. Visitors thought the worst impact would be hurricanes, followed by commercial fishing and then climate change. Water quality would be the most beneficial impact. However, using a seven-point scale with *4* being neutral meant that residents rated all

Table 6.12: Impact on ecological health of Florida Keys coral reefs

Mean Score	Recreational fishers		Snorkelers		Scuba divers	
	Residents	Visitors	Residents	Visitors	Residents	Visitors
Water quality	3.23	4.12	3.00	4.41	2.86	4.24
Scuba diving	3.43	3.54	3.57	3.96	3.80	4.09
Commercial fishing	2.66	2.54	2.74	2.85	2.97	2.97
Hurricanes	2.80	2.63	2.21	2.68	2.58	2.51
Snorkeling	3.49	3.56	3.76	3.96	3.85	4.00
Recreational fishing	3.65	3.64	3.29	3.49	2.92	3.37
Global climate change	2.70	3.05	2.36	2.80	2.23	2.81

Scale: 1 = extremely negative impact through 4 = neutral to 7 = extremely positive impact.

Source: Loomis et al. (2008 a,b,c)

Table 6.13: Rating current ecological health of Florida Keys coral reefs

Mean Score	Recreational fishers		Snorkelers		Scuba divers	
	Residents	Visitors	Residents	Visitors	Residents	Visitors
Poor = 1	19.0%	3.7%	19.4%	4.9%	30.0%	6.0%
Fair = 2	31.6%	27.3%	33.3%	24.2%	30.0%	28.2%
Good = 3	35.4%	46.9%	41.6%	42.5%	31.7%	38.9%
Very good = 4	15.7%	20.1%	5.6%	26.1%	6.6%	24.1%
Excellent = 5	1.3%	2.0%	0.0%	2.3%	1.7%	2.8%
Arithmetic mean	2.46	2.89	2.33	2.97	2.20	2.89

Source: Loomis et al. (2008 a,b,c)

impacts negative on average, and visitors fell short of an average of four on all criteria except water quality, despite their generally higher scores.

The current ecological health of the Keys coral reefs was rated poor by 22.8% of all residents surveyed (average of the three resident groups in Table 6.13), compared with only 4.9% of visitors. On average, residents rated reef health only slightly above fair (the mean of 2.33 for the three groups being one-third from fair moving towards good), whereas the central tendency for the three groups of visitors was close to "good" with an overall mean of 2.92.

Asked whether the ecological health of the reefs had changed (Table 6.14), residents again were harsher in their judgment than visitors: the arithmetic mean was close to 2, "declining somewhat" (the average for the three groups was 2.08, but resident snorkelers and scuba divers experiencing the reef direct took an even less favorable view than resident recreational fishers). Visitors thought on average that the health trend was about halfway between "declining somewhat" and "staying the same" (average 2.55), with not much difference between the three groups.

Table 6.14: Change in ecological health of Florida Keys coral reefs

Mean Score	Recreational fishers		Snorkelers		Scuba divers	
	Residents	Visitors	Residents	Visitors	Residents	Visitors
Declining substantially	20.3%	6.3%	23.7%	7.6%	35.6%	8.7%
Declining somewhat	44.3%	43.7%	60.5%	44.5%	37.2%	45.5%
Staying the same	22.8%	35.8%	10.5%	35.0%	13.6%	30.6%
Improving somewhat	11.4%	13.2%	5.3%	11.9%	13.6%	14.3%
Improving substantially	1.3%	1.0%	0.0%	1.0%	0.0%	1.0%
Arithmetic mean	2.29	2.59	1.90	2.54	2.05	2.53

Source: Loomis et al. (2008 a,b,c)

6.4 SOCIOECONOMIC MONITORING IN THE FLORIDA KEYS

The recreation and tourism part of the Socioeconomic Research and Monitoring Program for the Florida Keys is highly important in this future-orientated project. It was set up in the fiscal year 1998 to complement the Sanctuary's ecological monitoring program. A primary goal of the program is to detect and document resultant changes in sanctuary resource utilization patterns and their impact on market and nonmarket economic values of sanctuary resources. The problem of valuing these resources is discussed in Section 6.5.

The website, http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/, is headed sanctuary science. It has links to recreation and tourism, commercial fishing, marine zoning and reserves, knowledge, attitudes and perceptions of management strategies and regulations, and climate change – the last describing how the current project was modeled on an earlier study of the Great Barrier Reef (Hoegh-Guldberg and Hoegh-Guldberg 2004).

In the context of this section, the interest is in information that can be derived from changing variables or conditions, to evaluate possible futures for the Florida Keys for the scenario-building which follows in Chapter 7.

The backbone of the socioeconomic monitoring program is the surveys of visitors and residents in 1995-96 (Leeworthy and Wiley 1996a,b, 1997), and similar surveys for 2007-08 which became successively available for visitors from December 2009, when the initial results were presented (Leeworthy and Loomis 2009). Subsequently, Dr Leeworthy has made other essential results available as indicated below the individual tables in this section.

6.4.1 Visitors to the Florida Keys

The Florida Keys are visited for either recreation/leisure or other purposes. Those approached were only given a questionnaire if visiting for the former purpose (which defines them as tourists). The survey methodology, however, made it possible to identify the number who traveled to the Keys for other purposes. Based on the findings in Table 6.15, visitors fall overwhelmingly into the leisure category; moreover, their ratio to total visitors increased from 83% in 1995-96 to 92% in 2008-09. The number of other visitors declined by half between the two surveys.

Table 6.15: Total visitation, 1995-96 and 2007-08

	1995-96	2007-08	Change
Person-trips/visits			
Tourists	2.54	3.01	18.5%
Other visitors	0.52	0.26	-50.0%
All visitors	3.06	3.27	6.9%
Person-days			
Tourists	13.30	12.82	-3.6%
Other visitors	2.97	1.12	-62.3%
All visitors	16.27	13.94	-14.3%
Average length of visit (days)			
Tourists	5.24	4.26	-18.7%
Other visitors	5.71	4.31	-24.6%
All visitors	5.32	4.26	-19.8%

Source: Leeworthy and Loomis (2009), Table C.1

Based on the 1995-96 survey, an estimated 2.54 million visits or "person-trips" took place during that year. It increased to 3.01 million in 2007-08. These figures are the basis for estimates made in subsequent tables of this section, though there was a change in the definition of recreation in 2007-

Table 6.16: Mode of access of visitors, percentage shares

Mode of access	Based on person-trips		Based on person-days	
	1995-96	2007-08	1995-96	2007-08
Auto	78.7%	68.7%	83.4%	83.4%
Air	8.7%	5.2%	14.2%	9.5%
Cruise ship	12.7%	23.5%	2.4%	5.5%
Ferry	0.0%	2.6%	0.0%	1.6%
Total	100%	100%	100%	100%

Source: Leeworthy and Loomis (2009), Table C.2

08 to include "spa, health or wellness" activities. Using the 1995-96 definition, the increase in the number of visits for recreation purposes was reduced from 18.5% to 15%, and the decline in visits for other purposes was reduced from 50% to 34.6% (Leeworthy and Loomis 2009, p 4).

While noting this change, the basic story remains: more than nine of ten visitors to the Keys in 2007-08 came for recreation purposes, that is, as tourists. The remaining tables in this section concern these persons only.

The other crucial variable in the surveys is the number of "person-days" visitors spend in the Keys. In contrast to the number of visits in the top panel of Table 6.15, the total number of person-days declined: from 13.3 million in 1995-96 to 12.8 million in 2007-08 for tourists, or by 3.6%. The average length of time tourists stayed declined from 5.24 days in 1995-96 to 4.26 days in 2007-08, or by almost 20%.

The main mode of access for visitors is by car, though the share based on person-trips fell from 78.7% to 68.7% between the two survey years (Table 6.16). The largest increase in share of person-trips was for cruise ships, from 12.7% to 23.5%. Another sea-based mode, by the newly introduced ferries to Key West from Miami (since discontinued), Fort Myers and Marco Island accounted for 2.6% of person-trips in 2007-08. Finally, the share of person-trips by air fell from 8.7% in 1995-96, when Marathon Airport still received commercial flights, to 5.2% in 2007-08, when only Key West did so. The reduced share is not due to the cessation of commercial flights to Marathon: arrivals at Key West Airport were 18% lower in 2008 than in 1996 (Table 6.10).

Based on person-days, the automobile held its share at 83.4%, while there was a drop from 14.2% to 9.5% for air travel. Cruise ship passengers in Key West are day-travelers (by definition, they don't stay overnight on land). Their share of total person-days increased from 2.4% to 5.5% over the 12 years to 2007-08. Ferry passengers also stay for relatively short times in the Keys, showing a share of 1.6% of total person-days in 2007-08.

Tourists arriving by air tend to stay longer than other tourists (Table 6.17). While the average declined for both seasons, it was still as high as 8.6 days in the 2007 winter season and 6.4 days in the 2008 summer season. The average length of stay also declined for visitors arriving by automobile, to 6.5 days for the winter season and just under four days for the summer season during 2007-08. Ferry travelers stayed for shorter periods, and cruise ship passengers are defined as day travelers, as already noted.

Table 6.17: Average length of stay of visitors

Days per trip	1995-96		2007-08	
Mode of access	Winter	Summer	Winter	Summer
Auto	6.82	4.24	6.51	3.95
Air	9.04	7.65	8.63	6.40
Cruise ship	1.00	1.00	1.00	1.00
Ferry	-	-	2.50	2.97
All modes	6.03	4.17	4.94	3.51

Source: Leeworthy and Loomis (2009), Table C.8A

The shortening of the average length of stay ("person-days") is thus associated with two main factors: that both auto and air travelers stayed for shorter average periods in 2007-08 than in 1995-96, and because of the larger proportion of cruise ship passengers in 2007-08.

In addition to the changes in average length of visit and the pattern of access modes, the gender distribution has shifted towards a lower proportion of male respondents (from 72.8% to a still high 65.6%), and a higher average age (from 46.1 to 49.5 years). The age distribution is younger during the summer season when there are more families with children.

Table 6.18: Statistically significant changes in visitor profiles, 1995-96 to 2007-08

	1995-96			2007-08		
Socioeconomic/demographic indicator	Winter	Summer	Total	Winter	Summer	Total
Length of stay (days per trip)	6.03	4.17	5.17	4.94	3.51	4.26
Gender (male respondents/total)	71.6%	74.3%	72.8%	63.3%	65.6%	64.4%
Average age (years)	49.55	42.16	46.13	54.26	44.23	49.53
Median household income (2007-08 dollars)	na	na	$ 78,000	na	na	$102,000

Source: Leeworthy and Loomis (2009), Table C.8

Most strikingly, the median household income in 2008 dollars increased from $78,000 to an estimated $102,000 (Table 6.18). That is, more than half (50.9%) of those respondents who answered the income question were from households earning more than $100,000 in 2007-08. The comparable proportion for 1995-96 is unknown, but the consumer price index grew by about 37% between the two surveys, so the next highest income group, $60000-$99,999, would have been equivalent to about $82,000-$137,000 at 2008 values.

That group accounted for 30.4% of those answering the income question in 1995-96, while those earning $100,000 and over in that year accounted for another 15.8%. The proportion of visitors earning $100,000 or more in 2008 values back in 1995-96 would be at most 35%, and probably closer to 30%. The increase between the two surveys is indeed remarkable.

Another characteristic showing statistically significant change was race/ethnicity. There were increases in all groups other than "White not Hispanic", the largest being Hispanic growing from 4.8% to 5.8%, and Black, from 1.8% to 3.5%. The White group did show a statistically significant fall from 92.5% to 89.7% but the proportion remained numerically overwhelming.

Family composition and party size did not change significantly, but they revealed differences between the summer and winter seasons adding to the observations already shown in Table 6.18 for length of stay, and gender and age distributions. In 2007-08, the mean party size in the winter season was 2.40 persons, and in the summer season 3.17 (average 2.76), the

Table 6.19: Home address of visitors to Florida Keys

Residential address	1995-96			2007-08			Statistically significant?
	Winter	Summer	Total	Winter	Summer	Total	
South Florida Metro	8.8%	27.0%	17.2%	9.6%	20.7%	14.9%	Yes
Rest of Florida	7.6%	18.9%	12.8%	9.1%	14.8%	11.7%	Yes
Rest of USA	68.3%	35.3%	53.1%	65.7%	44.9%	55.9%	Probably
Foreign country	15.3%	18.8%	16.9%	15.6%	19.6%	17.5%	No

Source: Leeworthy and Loomis (2009), Table C.9.

average number of children was 0.12 in winter and 0.51 in summer (average 0.31), and the proportion of parties with no children 92.8% in winter and 71.9% in summer (average 82.8%). The summer season was demonstrably more family-orientated than the winter season in 2007-08, and also in 1995-96.

The winter and summer seasons also show some substantial differences for origin of visitors (Table 6.19). Though the difference diminished between 1995-96 and 2007-08, visitors from the nearest neighbor, the South Florida Metropolitan Area of Miami-Dade, Broward and Palm Beach Counties remained strongly inclined to visit in the summer season. So, to a slightly lesser extent, did visitors from the rest of Florida. Together, Florida made up 18.7% of winter visitors and 35.5% of summer visitors in 2007-08 (26.6% for the year).

The rest of the United States was attracted mainly during the winter season, when it accounted for 65.7% of all visitors in 2007-08 (down from 68.3% in 1995-96). It is natural to expect the attraction from the northern United States (and Canada) to be particularly strong during winter, since what is called winter in Florida is still balmy in comparison. However, in the summer season the proportion of visitors from the rest of the US was 44.9% in 2007-08, which represented a large increase from 35.3% in 1995-96.

For 2007-08 as a whole, visitors from the rest of the nation represented 55.9% of total visitors, which is probably a significant increase from 53.1% in 1995-96. The changes in the winter and summer seasons almost certainly would be statistically significant, but they went in opposite directions thus tending to cancel each other out. (The rest-of-US component was derived as a residual from Leeworthy and Loomis 2009, p 13.)

The 2007-08 survey found a small increase (from 16.9% to 17.5%) in the proportion of foreign visitors. It was not statistically significant. Canada was the largest group, increasing its share from 4.8% to 6.2% (winter), from 1.1% to 2.8% (summer), and from 3.1% to 4.6% for the year. These changes were all statistically significant. The second largest foreign group was the United Kingdom, increasing its winter visitation from 2.8% to 3.6% but dropping back in the summer from 4.2% to 3.0%. Both these changes were statistically significant whereas the overall change, from 3.5% to 3.3%, was not, since the two seasonal components pulled in opposite directions.

6.4.2 VISITATION PATTERNS, OVERNIGHT AND DAY VISITORS

The subject matter under this heading is the extent to which people stay in the particular district of the Florida Keys where they are accommodated, or whether they travel widely across the Keys. There are connections from this to whether the particular tourists are overnight or day visitors, as described below.

The five districts identified in the 2007-08 survey correspond to the districts used by the Monroe County Tourist Development Council (TDC), and also to the five Chambers of Commerce in Key Largo, Islamorada, Marathon, Lower Keys (Big Pine), and Key West. These districts also provided the geographic structure for the five scenario-planning workshops in 2008 (refer Appendices 1 and 2).

The 1995-96 survey combined Islamorada and Marathon, but the comparison in Table 6.20 compensates for the difference by eliminating visits to the two districts only. Thus, 12.5% of tourists visited Islamorada and 8.5% visited Marathon in 2007-08. The 21% total involved double counting of 1.5% of total visitors who visited the two districts only. They were eliminated to arrive at a comparison with 1995-96 (upper panel of Table 6.20).

Table 6.20: Visitation by TDC district, 1995-96 and 2007-08

TDC District	Survey year		Change	
	1995-96	2007-08	% points	Relative
Visited district				
Key Largo	35.9%	26.9%	-9.0	-25.0%
Islamorada	na	12.5%	na	na
Marathon	na	8.5%	na	na
Islamorada+Marathon	27.4%	19.5%	-7.9	-28.9%
Lower Keys	12.0%	6.5%	-5.4	-45.4%
Key West	55.8%	66.8%	11.0	19.7%
Visited one district only				
Key Largo only	22.1%	16.9%	-5.2	-23.6%
Islamorada only	na	5.4%	na	na
Marathon only	na	3.7%	na	na
Islamorada+Marathon only	14.2%	9.7%	-4.5	-31.7%
Lower Keys only	4.3%	1.6%	-2.7	-62.2%
Key West only	38.5%	53.0%	14.5	37.5%
Visited two or more districts				
Including Key Largo	13.8%	10.0%	-3.7	-27.2%
Including Islamorada	na	7.1%	na	na
Including Marathon	na	4.8%	na	na
Including Islamorada+Marathon	13.2%	9.8%	-3.4	-25.9%
Including Lower Keys	7.7%	4.9%	-2.8	-36.0%
Including Key West	17.3%	13.8%	-3.5	-20.2%

Source: Leeworthy and Loomis (2009), Table C.3

The upper panel of total visits counts any observation to any district. Someone visiting all four districts (in the 1995-96 definition before separating Islamorada and Marathon) is counted four times. The total number of observations adds to 131% of total visitors/tourists in 1995-96, falling to 120% for 2007-08. This indicates that tourists traveled less extensively within the Keys in the latter year.

The changes for each district are calculated in two different ways: by number of percentage points (yellow) and relative change in the distribution between 1995-96 and 2007-08 (light yellow). Both indicators show a solid shift towards Key West, away from the other districts, between the two survey years. The relative change in Key Largo was -25%, in Islamorada/Marathon -29%, and in the Lower Keys -45%. Key West shows a relative 20% gain, and a massive gain from 56% to 67% of the total observations.

The second panel shows tourists visiting only one district, which means that they are counted once only. Key West again stands out. As many as 53% of all tourists visited Key

West only in 2007-08 compared to 38.5% in 1995-96, a relative gain of 37.5%. The next most popular sole destination, Key Largo, experienced a decline from 22% to 17% of all tourists (relative loss 24%), Islamorada/Marathon a decline from 14% to 10% (relative loss 32%), and Lower Keys a decline from 4.3% to 1.6% (relative loss 62%).

The second panel adds to 79.1% of all tourists in 1995-96, and 81.2% in 2007-08. This means that the residual observations (bottom panel, which shows the top less the middle panel of Table 6.20) relate to those who visited more than one district, that is, 20.9% of tourists in 1995-96 and 18.8% in 2007-08. In 1995-96, the residual visits added to 52% of the number of tourists, or an average of 2.5 of the four identified districts visited. By 2007-08, the number of residual observations had fallen to 38.5% of tourists, so the number of districts visited per tourist was now just over two – a relative decline of almost 20% since 1995-96. All four identified districts in the bottom panel suffered declines, including Key West, as people traveled less within the Florida Keys during their visit.

The question is whether Key West's massive and increasing lead is mainly due to the fact that it receives the majority of day visitors as cruise ship passengers. Table 6.21 is similar to

Table 6.21: Overnight visitors' travel patterns

	1995-96			2007-08			Relative to total	
Thousand visits	Winter	Summer	Total	Winter	Summer	Total	1995-96	2007-08
Total overnight visitors	1,070.8	948.5	2,019.3	1,033.0	921.0	1,954.0		
Total districts visited								
Key Largo	408.6	375.6	784.2	294.8	365.7	660.5	28.3%	22.0%
Islamorada				180.5	148.5	329.0		13.5%
Marathon				150.2	91.4	241.6		11.2%
Islamorada+Marathon	325.6	313.1	638.7	*307.1*	*222.8*	*529.8*	23.1%	*22.9%*
Lower Keys	173.8	118.8	292.6	86.6	108.5	195.1	10.6%	6.5%
Key West	662.8	389.3	1,052.1	651.8	528.8	1,180.6	38.0%	48.6%
Total districts visited	1,570.8	1,196.8	2,767.6	1,340.3	1,225.8	2,566.0	100.0%	100.0%
Visited one district only								
Key Largo	195.9	262.9	458.8	148.4	222.1	370.5	16.6%	11.1%
Islamorada				73.1	54.5	127.6		5.5%
Marathon				61.0	43.4	104.4		4.6%
Islamorada+Marathon	117.4	210.7	328.1	134.1	97.9	232.0	11.9%	10.0%
Lower Keys	46.5	60.8	107.3	23.6	24.9	48.5	3.9%	1.8%
Key West	372.5	250.0	622.5	434.3	332.5	766.8	22.5%	32.4%
Total	732.3	784.4	1,516.7	740.4	677.4	1,417.8	54.8%	55.2%
Visited two or more districts								
Key Largo	212.7	112.7	325.4	146.4	143.6	290.0	11.8%	10.9%
Islamorada				107.4	94.0	201.4		8.0%
Marathon				89.2	48.0	137.2		6.7%
Islamorada+Marathon	208.2	102.4	310.6	*173.0*	*124.9*	*297.8*	11.2%	*12.9%*
Lower Keys	127.3	58.0	185.3	63.0	83.6	146.6	6.7%	4.7%
Key West	290.3	139.3	429.6	217.5	196.3	413.8	15.5%	16.2%
Total	838.5	412.4	1,250.9	599.9	548.4	1,148.2	45.2%	44.8%

Note: Minor discrepancies due to rounding included in residual bottom panel. Islamorada+Marathon estimated from ratio of 19.5/21.0 in top panel of Table 6.20 (estimates are shown in italics).

Source: Special tables compiled by Bob Leeworthy for overnight visitors, May 2010.

Table 6.20 showing the distribution of overnight visitors, with the added benefit of showing absolute numbers rather than percentage distributions.

The top line in Table 6.21 shows the total number of overnight visitors declining from 2.02 million in 1995-96 to 1.95 million in 2007-08 (-3.2%).

The top panel of Table 6.21 shows that the total number of districts visited by all tourists fell from 2.77 to 2.57 million (-7.3%).

According to the middle panel, 1.52 million overnight visitors visited one district only in 1995-96, falling to 1.42 million in 2007-08 (-6.5%). They represented 54.8% of total observations but 75.1% of total visitors in 1995-96, and 55.2% of total observations for 72.6% of total overnight visitors in 2007-08.

About 45% of overnight visitors visited more than one district in both years: about 502,600 persons in 1995-96 and 536,200 persons in 2007-08 (lower panel of Table 6.21). Between them they generated 1.25 million visits to districts in 1995-96 and 1.15 million in 2007-08 (Islamorada and Marathon adjusted to count as one). The average per overnight visitor was close to the finding for all tourists in Table 6.20: 2.5 in 1995-96 and 2.1 in 2007-08.

This leaves the change in distribution by districts. The top panel shows that even without the cruise ship passengers Key West increased its share of total observations from 38% to 48.6%. Key Largo lost share from 28.3% to 22%, Islamorada/Marathon held its share at 23%, and Lower Keys lost share from 10.6% to 6.5%.

Relating the observed numbers in the middle panel of Table 6.21 (visited one district only) to the top line of total overnight visitors, Key West increased its share from 30.8% to 39.2%, while other districts suffered losses: Key Largo from 22.7% to 19.0%, Islamorada and Marathon from 16.2% to 11.9%, and Lower Keys from 5.3% to 2.5%. These estimates can be compared with the observed shares in the middle panel of Table 6.20. For example, among

Table 6.22: Overnight and day visitation by mode of access

Access mode	1995-96				2007-08			
	Overnight	Day	Total	Day share	Overnight	Day	Total	Day share
Person-trips (number of visitors - thousand)								
Auto	*1,808*	*189*	1,997	9.5%	1,750	318	2,068	15.4%
Air	*212*	*9*	221	4.1%	150	6	157	4.1%
Cruise ship	-	323	323	100.0%	-	707	707	100.0%
Ferry	-	-	-	-	54	25	78	31.3%
Total	2,020	521	2,540	20.5%	1,954	1,056	3,010	35.1%
Person-days - thousand								
Auto	*10,898*	*189*	11,087	1.7%	10,372	318	10,690	3.0%
Air	*1,879*	*9*	1,888	0.5%	1,211	6	1,218	0.5%
Cruise ship	-	323	323	100.0%	-	707	707	100.0%
Ferry	-	-	-	-	181	25	205	12.0%
Total	12,777	521	13,299	3.9%	11,764	1,056	12,820	8.2%

Note: Figures in italics are estimates (day trips in 1995-96 for auto, and Key West and Marathon Airports).

Sources: Leeworthy and Loomis (2009), Tables C.1 and C.2, plus Leeworthy Tables C.10, C.14, 4.1, and 4.2

total visitors, 38.5% visited Key West only in 1995-96, growing to 53% in 2007-08. Key West accordingly did not just benefit from the increased number of cruise ship passengers.

Table 6.22 suggests that the number of person-trips (visits) associated with day visitors grew mainly as a result of cruise ship passengers. They made up 20.5% of all visits in 1996-97 and 35.1% in 2007-08. Cruise ships accounted for 62% of all day visitors in terms of person-trips in 1995-96, growing moderately to 67% in 2007-08, but the share of day visitors also increased substantially for people arriving by auto: 9.5% in 1995-96 and 15.4% in 2007-08. This contrasted with the number of arrivals of overnight visitors driving to the Keys falling from 1.8 million in 1995-96 to 1.75 million in 2007-08.

In terms of person-days, we arrive at a less dramatic picture, because both auto and air gets weighted with the average number of days staying in the Florida Keys. Day visitors arriving by air is by any measure a small proportion of total arrivals by air, and in the case of automobiles increased from 1.7% to 3% of total person-days, not a dramatic figure. Even for cruise ships, 323,000 person-days in 1995-96 accounted for only 2.4% of total person-days, rising to 707,000 or 5.5% in 2007-08.

6.4.3 Tourist activities

Visiting museums or historic areas emerged as the most strongly growing tourist activity in the Florida Keys between 1995-96 and 2007-08 (Table 6.23). The participation rate increased by 25% between the two years, and the number of participants nominating the activity grew from 837,000 to 1.24 million during the 12 years (48.4%).

Table 6.23: Activity participation rates and number of participants

	Participation rates			Thousand participants		
Activity/activity group	1995-96	2007-08	Change[1]	1995-96	2007-08	Change
Visiting museums or historic areas	33.0%	41.3%	25.4%	837.2	1,242.7	48.4%
Cultural events (fairs, concerts, plays)	7.4%	9.0%	21.4%	188.0	270.0	43.6%
Beach use	32.5%	27.6%	-15.0%	825.2	830.7	0.7%
Sightseeing and attractions	55.3%	45.0%	-18.5%	1,403.6	1,354.5	-3.5%
All diving	31.3%	23.7%	-24.1%	794.2	713.5	-10.2%
Boating	49.1%	35.0%	-28.7%	1,246.2	1,096.5	-12.0%
Viewing wildlife/nature	28.6%	19.9%	-30.5%	726.8	598.2	-17.7%
Fishing	21.0%	12.9%	-38.6%	534.4	388.4	-27.3%
Outdoor sports and games	4.1%	2.3%	-43.6%	103.1	68.7	-33.3%
Camping	7.8%	2.4%	-69.7%	198.8	71.1	-64.2%
Snorkeling	28.3%	21.8%	-23.0%	720.0	656.6	-8.8%
SCUBA diving	8.1%	4.9%	-39.3%	204.6	147.0	-28.2%
Any water-based activities	65.7%	53.0%	-19.3%	1,673.8	1,594.9	-4.7%
Any land-based actitivies	78.5%	78.7%	0.3%	1,994.6	2,368.1	18.7%
Only water-based activities	18.9%	11.0%	-41.6%	480.2	308.9	-35.7%
Only land-based actitivies	31.2%	35.1%	12.3%	793.5	1,107.7	39.6%

[1] Relative change (assuming constant total number of participants in 1995-96 and 2007-08). Activities in top box sorted according to percentage change in participation rates.

Source: Leeworthy and Loomis (2009), Tables C.4 and C.5.

Attending cultural events was the second-most strongly growing activity, but the actual number of participants was much lower.

Diving (both snorkeling and scuba), boating, viewing wildlife and nature, and fishing, all declined, whether measured as participation rates or number of participants. Overall, water-based activities declined in both participation rates and numbers, whereas land-based activities increased on both scores. Land-based activities continued to outnumber water-based activities, with 2.37 million compared with 1.59 million involved in 2007-08. A rapidly declining minority is involved in water-based activities only (309,000 in 2007-08) compared with a strongly growing number (1.1 million in 2007-08) participating in land-based activities only.

Table 6.24: Annual number of days spent on each activity

Thousand days	1995-96	2007-08	Change
Snorkeling	1,702.5	1,854.4	8.9%
SCUBA diving	534.5	451.8	-15.5%
All diving	2,237.0	2,306.2	3.1%
Fishing	1,949.8	1,312.1	-32.7%
Personal watercraft use	378.4	264.6	-30.1%
Sailing	217.7	162.6	-25.3%
Other boating	260.7	273.2	4.8%
Viewing nature and wildlife from land	1,789.8	1,524.5	-14.8%
Viewing nature and wildlife from water	855.4	661.0	-22.7%
All viewing nature and wildlife	2,645.2	2,185.5	-17.4%
All beach activities	2,688.6	3,162.9	17.6%
Windsurfing or sailboarding	24.4	17.8	-27.0%
Swimming in outdoor pools	2,489.2	2,379.3	-4.4%
Visiting museums and historic sites	1,695.3	2,592.6	52.9%

Source: Table C.10 (received from Bob Leeworthy in May 2010)

Table 6.24 suggests that the number of days spent on diving increased marginally between 1995-96 and 2007-08 due to increased snorkeling (despite a declining number of participants), with scuba diving declining. Fishing declined by 33% in terms of time used, boating presented a mixed picture, and viewing nature and wildlife either on land or water were declining activities measured by time used. Beach activities increased, but the strongest growth remained visiting museums and historic sites.

6.4.4 Economic impact of tourism

At constant-value dollars, spending per person per trip declined by 2.7% between the two surveys, and by 3.5% per person-day. Spending per person per trip was higher during the winter than summer season, but both declined, marginally in winter and more strongly in summer. Daily spending per person declined by 14.3% during the winter season but increased by 12% during summer. Spending increased whether per person-trip or per person-day for people arriving by car or into Key West International Airport. Spending fell strongly (on land) for cruise ship passengers (Table 6.25).

Table 6.25: Visitor spending in Monroe County

Dollars at 2008 values	Per person per trip			Per person per day		
	1995-96	2007-08	Change	1995-96	2007-08	Change
Total	$ 623	$ 606	-2.7%	$ 149	$ 144	-3.5%
By season						
Winter	$ 671	$ 669	-0.4%	$ 159	$ 136	-14.3%
Summer	$ 566	$ 536	-5.3%	$ 138	$ 155	12.0%
By mode of access						
Auto	$ 692	$ 711	2.7%	$ 147	$ 158	7.5%
Air - Key West	$ 1,652	$ 1,716	3.9%	$ 201	$ 258	28.4%
Cruise ship	$ 138	$ 84	-39.1%	$ 129	$ 84	-34.9%
Ferry	na	$ 301	na	na	$ 115	na

Source: Leeworthy and Loomis (2009), Tables C.6 and C.6A.

The impact on the Monroe County economy was calculated in meticulous detail by Bob Leeworthy and includes not only the trip costs identified in the surveys but also the annual expenditure by people owning or leasing condominium and time share facilities (the dominant item), marina storage services, and recreational vehicle/trailer parks. The impact also includes estimated multiplier or "ripple" effects of the primary expenditure in Monroe County (Table 6.25). Total tourist spending in the County, after adjusting for inflation, increased by 22% over the 12-year period (Table 6.26). The economic impact or contribution to the Monroe County economy of this spending increased by 22.5% in terms of total sales or output, 40% of extra income to Monroe County residents, and 47% of additional jobs.

These findings are compatible with the changes to the Monroe County economy observed in Table 6.4, which showed an upward trend in personal income adjusted for inflation, and Table 6.6 showing structural change: declining retail and hospitality service employment and a strong increase in real estate employment suggesting much increased activity in that sector.

Table 6.26: Total impact of visitor spending on Monroe County economy

Million dollars at 2008 values	Including multiplier effects			Proportion of economy	
	1995-96	2007-08	Change	1995-96	2007-08
Total spending	1,630	1,990	22.1%		
Total sales/output	1,820	2,230	22.5%	60.5%	59.9%
Total income	693	970	40.0%	45.0%	46.9%
Total employment (thousand full-time and part-time jobs	21.8	32.0	46.8%	46.5%	57.0%

Source: Leeworthy and Loomis (2009), Table C.7

The total sales or output generated by tourism was about 60% of the total Monroe County economy in both 1995-96 and 2007-08. It represented 45-47% of the total income of the County, and 46.5% of the total number of full-time and part-time jobs in 1995-96, rising to 57% in 2007-08 (Table 6.26).

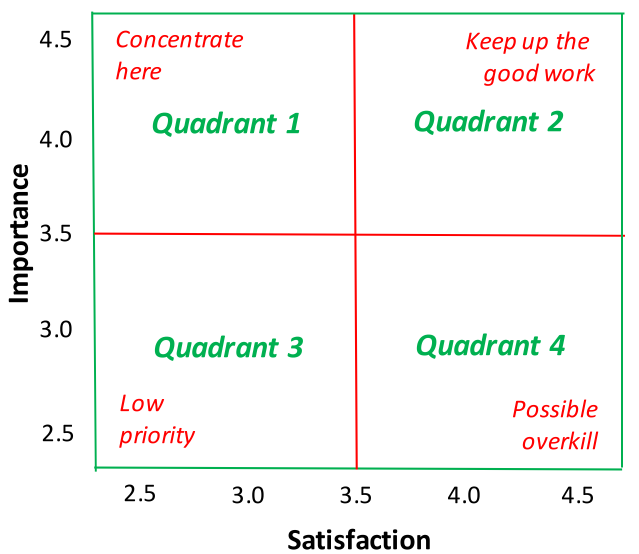
6.4.5 IMPORTANCE AND SATISFACTION RATINGS

One of the major contributions of the surveys are the ratings that visitors (and residents) put on a range of resources, facilities and services, using an approach originally developed for marketing purposes but widely adopted as a planning tool. The ratings have two dimensions for each item: importance to the respondents, and how satisfied they are. Both use five-point scales with the highest importance and satisfaction scores rated highest.

Combining the average importance and satisfaction ratings for a total sample or its subgroups results in a matrix with importance and satisfaction as its two dimensions (Figure 6.4). The matrix is divided into four quadrants combining the ratings. An average rating of 3.5 is used as a dividing mark between what is rated important and not important, and what is rated satisfactory and less satisfactory.

While this provides an important guide to priority setting, the tool could be further developed to target specific groups, rather than concentrating on total groups of surveyed residents of or visitors to the Florida Keys. It is of course a good democratic principle to ask everyone, and an important criterion in its own right. But it would also be interesting to analyze these combined ratings for selected groups, say, of opinion leaders or other people potentially capable of influencing political decisions directly. This could be done separately, outside the framework of major surveys.

Figure 6.4: Importance-satisfaction matrix



Source: From Leeworthy et al. 2004

Visitors and residents were asked in the surveys how important each of 25 resources, facilities and services were to them, using the scale from "unimportant" (1) to "extremely important" (5). The satisfaction scale runs from "very dissatisfied/terrible" (1) to "very satisfied/delighted" (5). The dividing mark on the importance scale of the matrix falls between "important" (3) and "very important" (4), and for satisfaction between "neutral" (3) and "somewhat satisfied" (4). Table 6.27 compares the averages for the two surveys, and which quadrant of Figure 6.4 they would fit into. Quadrants 1 and 2 identify the items rated above 3.5 on importance, with Quadrant 1 indicating which ones are below a satisfaction rating of 3.5. Table 6.27 also shows any statistically significant changes in ratings between 1995-96 and 2007-08, as calculated by Dr Leeworthy for the source tables.

There are four groups of items in Table 6.27, each sorted according to its importance in 2007-08. Of seven natural resource items, five were rated above the 3.5 mark for importance, with the averages for two items, quality of beaches and clear water, above 4 (very important). The least important item was opportunity to catch fish and other sea life, where the importance rating fell significantly since 1995-96. The rank order, and general magnitude of the averages, was otherwise similar between the survey years.

The satisfaction ratings for natural resources were above the 3.5 mark, except for opportunity to see large wildlife, and quality of beaches which was a borderline case. Both are in Quadrant 1 (high priority) in the source tables. One item, clear water, was rated significantly more satisfactory in 2007-08 than in 1995-96. Opportunity to catch fish and

Table 6.27: Average importance and satisfaction ratings by tourist visitors

Statistically significant change between surveys shown in bold italic color	Importance ratings		Satisfaction ratings		Quadrant
	1995-96	2007-08	1995-96	2007-08	2007-08
Natural Resources					
Quality of beaches	4.17	4.21	3.45	3.51	***1***
Clear Water (high visibility)	4.07	4.05	***3.82***	***3.96***	***2***
Amount of living coral on reefs	3.84	3.93	3.73	3.75	***2***
Many different kinds of fish and sea life to view	3.77	3.84	3.77	3.81	***2***
Opportunity to view large wildlife (manatees, whales, dolphins, sea turtles)	3.62	3.72	3.34	3.40	***1***
Large numbers of fish	3.50	3.46	3.52	3.56	3
Many different kinds of fish and sea life to catch	***2.88***	***2.69***	3.59	3.67	4
Natural Resource Facilities					
Parks and specially protected areas	3.93	4.02	***3.75***	***3.85***	***2***
Designated swimming/beach areas	***3.72***	***3.90***	3.38	3.43	***1***
Shoreline access	3.82	3.88	3.35	3.42	***1***
Mooring buoys near coral reefs	***3.35***	***3.16***	3.83	3.83	4
Marina facilities	***2.67***	***2.45***	3.71	3.79	4
Boat ramps/launching facilities	***2.56***	***2.35***	3.61	3.67	4
Other Facilities					
Availability of public restrooms	***3.82***	***4.05***	***3.30***	***3.40***	***1***
Cleanliness of streets and sidewalks	***3.79***	***3.91***	3.66	3.69	***2***
Historic preservation (historic landmarks, etc)	***3.72***	***3.86***	***3.88***	***4.05***	***2***
Directional signs, street signs, mile markers	3.72	3.67	3.64	3.72	***2***
Conditions of roads and streets	3.64	3.66	3.62	3.65	***2***
Condition of bike paths and sidewalks	3.51	3.59	3.64	3.67	***2***
Uncrowded conditions	3.52	3.58	***3.43***	***3.60***	***2***
Parking	***3.29***	***3.42***	3.34	3.27	3
Public transportation	2.27	2.39	3.35	3.49	3
Services					
Customer service and friendliness of people	***4.14***	***4.29***	***3.91***	***3.99***	***2***
Value for the price	***4.12***	***4.25***	***3.28***	***3.44***	***1***
Maps, brochures, and other tourist information	3.39	3.49	***3.85***	***3.96***	4
All Items	3.55	3.59	3.59	3.66	

Mean scores: Scale from 1 to 5 with 5 meaning extremely important/extremely satisfactory.
Statistical significance at 95% confidence level.

Source: Leeworthy Tables C.11, C.12 and C.13 supplied in May 2010.

other sea life was the only item among the natural resources to fall into Quadrant 4 (ironically, for this particular activity, called “possible overkill”).

The second group of items consists of six natural resource facilities. The average importance rating for parks and specially protected areas exceeded 4 (very important), and it also enjoyed a significant increase in satisfaction ratings. It falls into Quadrant 2 (“keep up the good work”). The second-most important item was designated swimming and beach areas, for which the rated importance increased significantly over the period. Both this and the third item, shoreline access, were considered relatively unsatisfactory, putting them in the high-priority Quadrant 1.

There was a significant decline in the rated importance of the three remaining items: mooring buoys near coral reefs, marine facilities, and boat ramps (though the rating remained above 3 for mooring buoys). There was relative satisfaction with all three items, and all fit Quadrant 4 (possible overkill).

Other facilities are installed to improve the comfort of tourists (and local citizens), such as public restrooms, the condition and cleanliness of streets, sidewalks and bike paths, signs and mile markers, uncrowded conditions, parking, and public transport. They were generally regarded as important, some significantly more so in 2007-08 than in 1995-96. They also received relatively high and often rising satisfaction ratings, and generally fit into Quadrant 2 (“keep up the good work”). The exceptions were public restrooms, regarded as very important with an average of 4.05 but relatively unsatisfactory despite a significant increase in the average satisfaction rating in 2007-08 (Quadrant 1), and parking and public transport being rated relatively unimportant as well as relatively unsatisfactory (Quadrant 3).

This leaves the odd item among “other facilities”, historic preservation. This was not only considered highly and increasingly important but also received the highest satisfaction rating of all the items in Table 6.27 (4.05). Both ratings for historic preservation improved significantly between 1995-96 and 2007-08.

Three services include the highest importance ratings of all items in the opinion of tourists. They are customer service and friendliness of people, and value for the price. Both showed significantly increasing satisfaction ratings of above 4.2 in 2007-08. Their satisfaction ratings also increased significantly though remaining below 3.5 for value for the price (Quadrant 1).

Summing up, this project is primarily concerned with natural resources and associated facilities, but if the Keys are to preserve a healthy tourist industry, we must also recognize the importance of the tourism infrastructure listed under other facilities in Table 6.27. This includes both the provision of a comfortable and attractive human-made environment, and the preservation of the historic heritage in Key West and elsewhere.

Among the natural resources, it would have been reassuring to see an increase in the importance ratings for amount of living coral and for the biodiversity of the reef, but there was no improvement in this respect over the 12 years between the surveys. Among the natural resource facilities, the high rating of parks and specially protected areas was a positive sign, but the drop in the perceived importance of mooring buoys coupled with a high satisfaction rating (suggesting a degree of complacency, or a loss of knowledge as activity patterns change?) was a little disturbing. It seems to be part of the general change from sea-based to land-based activities identified in Section 6.4.3.

6.4.6 Resident surveys

The 2007-08 survey of residents, which was carried out in parallel with the visitor survey, was not yet available when this report was completed. The most important part of the resident survey from our point of view is likely to be the importance and satisfaction ratings and the extent to which these differ from those of the visitors.

It is more than likely that residents will rate key features more highly on importance and will be less satisfied with the current state of affairs. This was the general outcome of the UMASS Amherst studies reported in Section 6.3.3 (Loomis et al. 2008a,b,c) – more pronounced for snorkelers and scuba divers than for recreational fishers but apparent for all three.

It was also the finding of the 1995-96 surveys. Table 6.28 shows average importance and satisfaction ratings for residents and visitors, and the difference between the two. The comparison is limited to the eight items considered most important by residents. The difference between importance ratings for residents and visitors was highest for amount of living coral (which residents rated almost halfway between very important and extremely important with an average score of 4.47), and mooring buoys.

Satisfaction ratings were generally higher among visitors (with the exception of parks and specially protected areas) with the largest difference for amount of living coral on reefs. The coral indicator is particularly striking in demonstrating a difference between residents' and visitors' perceptions. It will be interesting to find out from the 2007-08 resident survey, when ready, whether their importance ratings have remained intact since 1995-96.

Table 6.28: Comparison of visitors' and resident's mean importance/satisfaction scores, 1995-96

All criteria where residents rated importance at 4 or more	Residents		Visitors		R - V	
	I	S	I	S	I	S
Clear Water (high visibility)	4.40	3.50	4.21	3.81	0.19	- 0.31
Amount of living coral on reefs	4.47	3.23	3.96	3.75	0.51	- 0.52
Many different kinds of fish and sea life	4.22	3.49	3.94	3.83	0.28	- 0.34
Quality of beaches	4.26	3.00	4.13	3.38	0.13	- 0.38
Parks and specially protected areas	4.06	3.51	3.92	3.38	0.14	0.13
Mooring buoys near coral reefs	4.31	3.63	3.66	3.88	0.65	- 0.25
Service and friendliness of people	4.21	3.46	4.13	3.87	0.08	- 0.41
Value for the price	4.14	2.84	4.17	3.31	- 0.03	- 0.47

Source: Leeworthy and Wiley (1996,a,b).

Late addition, November 2010: The eight attributes in Table 6.28 also scored importance ratings above 4 from residents in 2008, scores that significantly exceeded their satisfaction ratings, especially the assessment of living coral on reefs (importance rating 4.34, satisfaction rating 3.06). Residents placed greater importance than visitors on mooring buoys (a gap of 0.90 scores), variety of fish and sea life (gap 0.41), living coral (gap 0.40), and clear water (gap 0.23). Relative to visitors, residents were least satisfied with the amount of living coral (3.06 against 3.75 for visitors), but they were scored consistently lower on all eight attributes (details in Leeworthy and Morris (2010) and Leeworthy and Ehler (2010a)).

6.4.7 MAIN CHANGES OBSERVED IN THE SURVEYS

- There has been a declining trend in the average number of days people visit the Florida Keys as tourists, from 5.3 days in 1995-96 to 4.3 days in 2007-08. This was not only due to an increase in the number of day visitors (cruise ship passengers in Key West), but also to a decline in the average stay of people arriving by auto and air.
- So, despite an increase in the number of person-trips (visits) from 2.5 million in 1995-96 to 3 million in 2007-08, the total number of person-days declined from 13.3 million to 12.8 million.
- As well as day travelers visiting only one district (increasingly representing cruise ship passengers), overnight visitors were also less mobile in 2007-08 than in 1995-96. This is probably partly associated with a decline in sea-based activities including diving and recreational fishing, while land-based activities such as visiting museums and historic areas have increased strongly. This all favors Key West over Key Largo and other districts. With less incentive to engage in sea-based activities, however, it is not surprising that the average length of visits has fallen.
- Spending by visitors per person-day in constant 2008 dollars declined slightly from $149 in 1995-96 to $144 in 2007-08. However, total sales/output including multiplier effects increased by an estimated 22.5% between the two survey years, to $2.26 billion, representing 60% of the total Monroe County economy. The main reason was a strong increase in the number of tourists owning or leasing their own condominiums or time-share facilities, a sign of the structural change that has become evident in the Keys.
- Importance and satisfaction ratings by tourists are increasingly associated with infrastructure facilities and services, while coral reef health and biodiversity are not gaining importance. However, local residents take a significantly stronger view on reef health than tourists, and are less satisfied with the state of coral reef health.

6.5 VALUING ECOSYSTEMS

This section starts with an overview of the links between the environment and the economy and the importance of extending the analysis to nonmarket values to capture these links better. Section 6.5.2 then demonstrates the difficulty of doing this in practice, referring to a study carried out on the Great Barrier Reef in Australia in 2009. Section 6.5.3 describes the valuable work for the Florida Keys extending over many years within NOAA's National Ocean Service. Section 6.5.4 proposes that the methodologies involved in valuing these ecosystems can be applied, with important modifications, to conditions of rapid climate change.

6.5.1 ENVIRONMENTAL QUALITY AND THE ECONOMY

We noted at the beginning of Section 6.4 that a primary goal of the Florida Keys Socioeconomic Research and Monitoring Program is to document changes in sanctuary resource utilization patterns and their impact on the economic values of sanctuary resources. In this context, linking the economy to the environment involves estimating the market and nonmarket economic values of recreation/tourist use of the Florida Keys ecosystem, demonstrating how these ecosystem values form an integral component of the economy when formulating sustainable development objectives and policies, and fostering cooperative management processes (Leeworthy and Bowker 1997, p ii).

Market economic values (sales/output, income, employment) are not good leading indicators of the long-term health of natural resources, because these values can increase in the short term by exploiting natural capital. The same applies to nonmarket economic values (consumer surplus) which can continue to increase for a while for similar reasons.

The level of sustainable use is a function of technology, individual behavior patterns, and institutions. Economic opportunities can be expanded by investments in technologies, behavioral changes, and institutional change that alter the relationships between environmental quality and use.

Environmental indicators can be better leading indicators of the long-term health of the natural resource-dependent economy (Leeworthy and Bowker 1997, p 2).

6.5.2 Total Economic Value approach to reef valuation

In Australia, the Great Barrier Reef Foundation in 2009 commissioned a study of the cost of total permanent bleaching of the GBR (Oxford Economics 2009). The report correctly states that using a Total Economic Value (TEV) approach is a broader concept than market-based valuation within a conceptual national accounting framework. The latter, especially in the conventional manner in which it is currently practiced, only identifies direct market-based uses. The TEV is the sum of what is termed producer surplus (profit) and consumer surplus (how much users and non-users are *willing to pay* to *visit* and *preserve* the reef).

This provides a framework for going past the purely market-based economic approach. Furthermore, since the reef is a long-lived natural resource, the benefits stretch into the future using a present-value approach derived via the use of a social discount rate. This, according to Oxford Economics, fits in with the emergence of climate change and its effects, which has "focused policymakers' minds on the long term effects of natural resource degradation on the broader economy as well." (p 16)

TEV consists of *use and non-use values*. *Direct market-based uses* of the GBR can be measured for tourism and fishing and any other industry, provided the appropriate data have been assembled. The focus here is on operating surplus or profit (*producer surplus*). However, use values also includes estimating how much more consumers would be willing to pay to experience the reef, giving rise to a *consumer surplus*.

Indirect use values need to be estimated from elsewhere. In the GBR report, they consist of "ecosystem services" protecting adjacent coastal areas from storms.

There are three main types of *non-use values*, which are not easy to distinguish in practice, and not even in concept judging from the descriptions below. The descriptions have been augmented with references from Bob Leeworthy's presentation to the FRRP Reef Resilience Conference in Key Largo on the economics of coral reef ecosystems (Leeworthy 2008).

Option values, according to the GBR report, are attached to potential future gains, for example new substances which point toward prospects for medical/pharmaceutical benefits that have not yet been identified. Leeworthy (2008) defines option values as current non-users' willingness to pay to ensure a resource is protected or restored to a certain condition so they might use it in the future – a kind of insurance policy. He calls the value we might obtain from future discoveries like medicinal properties of the corals a *quasi-option value*, like scientific value and educational value.

A *bequest value* is the value which members of the current generation place on preserving the GBR for the benefit of future generations. Leeworthy (2008) refers to the bequest value as the willingness to pay for future generations to have the opportunity to experience the resource in a certain condition or preserving its *existence value*, being willing to pay to simply know that a resource will be protected or restored to a certain condition. Existence values, as their name implies, are attached to the existence of the GBR, whether or not the person who makes the valuation ever visits it.

Figure 6.5 shows the connection between a current average price or cost of visiting the reef and the number of tourists paying this price. The supply curve describes the minimum price producers are willing to offer for reef visits, and the demand curve the maximum price consumers are willing to pay. The consumer and producer surpluses are indicated by the colored areas of Figure 6.5.

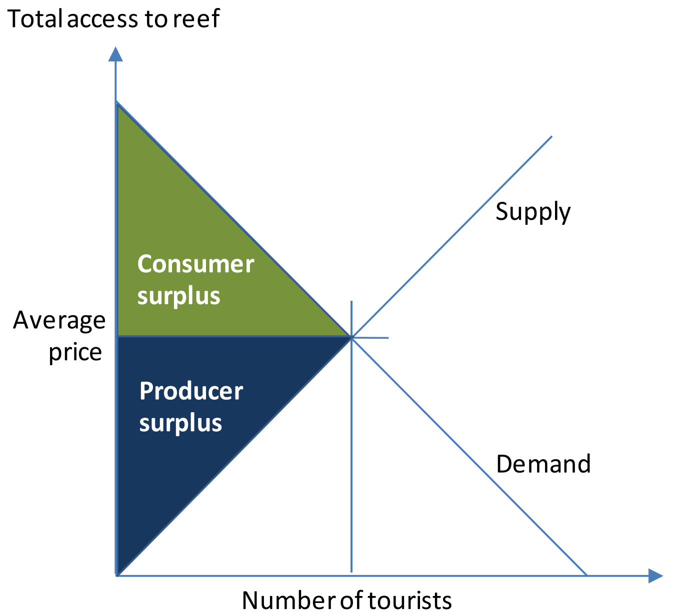


Figure 6.5: Producer and consumer surpluses for tourism. The producer surplus (roughly equal to profits) is the difference between the price received by suppliers (the average price line) and the minimum price at which they would have been willing to sell commodities (in this case "reef visits") – i.e. the supply line. This represents the benefit to industry from the fact the GBR exists, and is captured by the blue area between the price line and the supply curve. The consumer surplus represents the difference between what consumers pay and the maximum price they would be willing to pay, in this case for a reef visit (the demand curve). It is represented by the olive green area between the price line and the demand curve. Source: Oxford Economics (2009), pp 18-19.

The TEV approach in the Oxford Economics report involved holding all variables constant in real terms through the 100 years, including the current value of tourism, industry profits, and non-use values. Bleaching was assumed to be total from 2009 through the projected period to 2108. The present value of the GBR was an estimated $51.4 billion, and the present value cost of total bleaching $37.7 billion. The remaining value with a bleached reef was $13.7 billion. The Australian dollars shown here averaged 79 US cents in the base year of 2009. The estimates were based on a "preferred" discount rate of 2.65%, streamed over 100 years. The

Oxford Economics reports adds that the direct loss from a totally bleached GBR is equivalent to an annual $1.08 billion through the century.

The components of the TEV demonstrate the difficulties of obtaining a reliable database:

- *Tourism consumer surplus from reef-motivated visits to coral sites*: Present value $16.6 billion, present value cost of total bleaching $16.6 billion. All lost (excluding tourism to North and Central Queensland which was not attracted by the reef and therefore not part of the model). It was estimated from a range of studies that at least 50% of overnight visitors, and all domestic day visitors, who visited the coral sites would have not have done so if the GBR sites had suffered (p 23 et seq.). The tourism value was assessed by the travel-cost method using data from official tourism surveys.

- *Tourism producer surplus (profit) from reef-motivated visits to coral sites*: Present value $3.6 billion, all lost. This appears to be based on a fair empirical database.

- Recreational fishing consumer surplus from assessed value in the GBR Marine Park: present value $2.5 billion, none lost. "Recreational fishers appear to be largely motivated by "the experience not the catch"; it is uncertain if values would be materially impacted by bleaching." (p 23)

- *Recreational fishing producer surplus* (profit) from assessed value of regional fishing supplies: present value $0.3 billion, none lost. This covers supplies to recreational fishers and therefore reflects the assertion that the present value of recreational fishing would not be affected.

- *Commercial fishing producer surplus* (profit) from assessed value of commercial fishing within the GBR Marine Park: present value $1.4billion, cost $0.4 billion. This is based on what was seen as the most conservative loss estimate, which happened to be Hoegh-Guldberg and Hoegh-Guldberg (2004), that 30-36% of catches would be lost to bleaching. However, this estimate only covered the period up to 2020, with further losses to come, whereas the model used by Oxford Economics covers 100 years.

- *Indirect use value from assessed value of GBR as a physical barrier*: present value $10.0 billion, none lost. "Bleaching of the GBR may result in the eventual loss of some of this protection function. However, this is likely to be a long term process and no immediate impact has been estimated for this report." (p 42) "Further, from a practical point of view, even the effects of a relatively rapid (i.e. 30-50 years) reef destruction following bleaching would be considerably reduced by discounting." (p 46) See comments below.

- *National non-use value* from assessed value of coral sites and interrelated ecosystems. Present value $15.2 billion, all lost. The estimate was based on a comprehensive but dated study from 1987 and a 2005 project that covered only the Fitzroy Basis in the extreme south, where Brisbane households were asked how much they would be willing to pay for changes to the water quality of the Fitzroy estuary which is connected to and has a direct impact on the GBR lagoon (p 49).

- *International non-use value* from assessed value of coral sites and interrelated ecosystems. Present value $1.9 billion, all lost. This was based on a study of rainforests in the absence of data on coral reefs. The Oxford Economics authors note that GBR is world heritage and a global resource, “On *a priori* grounds there must .. be a positive global [willingness to pay] for preserving the GBR as a part of the global ecosystem (i.e. as a “global public good”)”. (p 53) But it is admitted in the report that the area is not well researched.

The competence of the Oxford Economics team is not an issue here, but clearly the lack of good data makes this type of analysis very difficult, and causes the results to be based on controversial assumptions. The estimated producer and consumer surpluses for tourism are probably the most solid. Further comments follow on other components:

- The evidence presented for recreational fishers in the report (p 33) suggests that some are concerned with whether or not they have a catch, which means that there might be an impact on the present value in the absence of a living reef. We add from the evidence of the Florida Keys surveys that the number of recreational fishers there has been declining, along with the coral cover diminishing. This suggests that the present value of recreational fishing would be lower, probably much lower, in a totally bleached GBR.
- To assume that commercial fishing would be reduced by only 30% if the reef dies is also based on questionable assumptions. In a study with a 100-year time frame it does not appear to make sense to measure the impact of the bleaching from a short period. Again, the evidence from Florida shows that the number of commercial fishers has dropped substantially along with the catch.
- To assume that the reef will continue to provide full protection to the Queensland coast appears to be overly optimistic, especially if ocean acidification and the likelihood of more violent storms are added as factors – something not assumed in the Oxford Economics report which does not mention acidification though it does cite examples of the reef being protected from cyclones in the past. A report commissioned by the Australian Garnaut Climate Change Review (Hoegh-Guldberg and Hoegh-Guldberg 2008, p 12) states:

  “If atmospheric CO_2 increases beyond 450 ppm, large-scale changes to coral reefs would be inevitable. Under these conditions, reef-building corals would be unable to keep pace with the rate of physical and biological erosion, and coral reefs would slowly shift towards non-carbonate reef ecosystems. .. As a result, the three-dimensional structure of coral reefs would slowly crumble and disappear. Depending on the influence of other factors such as the intensity of storms, this process may happen at either slow or rapid rates. It is significant to note that this has happened relatively quickly (over an estimated 30 to 50 years) on some inshore Great Barrier Reef sites. .. Loss of the calcium carbonate framework would also have implications for the protection provided by coral reefs to other ecosystems (e.g. mangroves and sea grasses) and human infrastructure, .. .“

  The principal author of the statement has not changed his opinion (Ove Hoegh-Guldberg, personal communication, May 2010).

  The assertion by the Oxford Economics authors that the chosen social discount rate would greatly diminish the weight of future years in the calculation of present values, raises questions about why in that case a 100-year period was chosen for the analysis, and whether the social discount rate should be lower, given that the rationale of the project was provided by the potential impact of climate change, which is referred to in numerous contexts in the report. See further Section 6.5.4.

6.5.3 The Florida Keys context

Designating a National Marine Sanctuary implies that the area and its resources are unique. “The stewardship of these sanctuaries are of national importance, yet involves a broad range of local concerns that affect the valuation process.” (Wiley 2003, p 1) It was described in Section 4.3 how sanctuary resource management involves multiple overlapping jurisdictions including national, state and local government instrumentalities, as well as other stakeholder groups across a wide geographic range.

“The ways in which these various stakeholders value the resources are as disparate as their reasons for participating in their management. However, the most difficult stakeholder group’s value to take into consideration is the US population as a whole. As a national resource, every citizen holds a claim to ownership of sanctuary resources. However, most of the attention is often paid to local stakeholders who use the resource directly.” (Wiley 2003, p 1)

The chief economist of NOAA’s Office of National Marine Sanctuaries, Bob Leeworthy, leads the effort to introduce nonmarket values into the economic analysis of the tourist and recreation activities in the Florida Keys, and elsewhere. The theoretical approach is similar to that taken in the Oxford Economics study of the Great Barrier Reef (effectively using a TEV or Total Economic Value model), but the insights of two decades or more of research add significantly to the approach due to a closer association with local issues of environmental quality and superior long-term general knowledge of the study area. Even so, Leeworthy (2008) notes:

“We have not estimated these [passive economic use] values for coral reefs anywhere in the world. However, we are currently doing this for Hawaii’s coral reef ecosystem. In the Tortugas Ecological Reserve, we used a “policy analysis” employing conservative lower bound estimates of what these values might be, *and they exceeded all direct use values.”* (Italics added.)

Sustainable development depends on maintaining or increasing the natural capital stock of the area. Natural capital stock is represented by the quality of the environment and the abundance and diversity of the natural resources of the area. In the long run, market and nonmarket economic values will decline if environmental quality declines (Leeworthy and Bowker 1997).

Asset value is defined as the amount someone would be willing to pay today if they could own the reef resources and charge a price for their use. “It is like the value of a house or a car in which the asset has a certain life and it yields a stream of services over the life of the asset. But at any point in time there is a price someone would be willing to pay to own it.” (Leeworthy 2008).

This is a central concept because it is associated with the purpose of the valuation. The approach up to this point has been to determine the asset value of the reefs for recreational use, using the following conservative lower-bound assumptions:

- The reefs have an indefinite life (perpetuity)
- Future annual reef use is constant, since we are unable to forecast very far into the future
- The future annual user value per unit of use is also constant in view of our inability to estimate people's preferences far into the future
- A real discount rate of 3% is used to convert future dollars to current dollars.

As discussed in Section 6.5.2, there are two categories of nonmarket values. In NOAA's understanding of economic welfare theory, the categories are the consumer surplus and a special sub-category of producer surplus, economic rent, which is relevant in the context of economic efficiency. Economic rent is the return on investment above "normal" returns on investment. In an open competitive environment, economic rents won't exist for long as new entrants will be attracted by the relatively high returns on investment. But there are time lags and other dynamics that delay the movement toward an equilibrium, and the higher return on investment can also persist when governments pass regulations that limit entry, for instance by prohibiting further draining of wetlands to build or expand marinas.

"Nonmarket user values for visits to the Florida Keys/Key West are determined, in part, by environmental quality. Increases in environmental quality would increase the demand for recreation/tourism." (Leeworthy and Wiley 1997, p 9) This would result in an upward shift in the demand curve and a resulting increase in both use value and consumer surplus (nonmarket economic use value). Figure 6.6 illustrates this effect, but we have noted in the description below the graph that the demand (up from Q_1 to Q_2 as shown) would eventually shift downward if environmental quality deteriorated.

The consumer surplus is what consumers receive from the consumption of a good or service over and above what they hope to pay for it. Since no one owns the reef resource, the estimated consumer surplus is itself the annual direct economic use value of the reef resource.

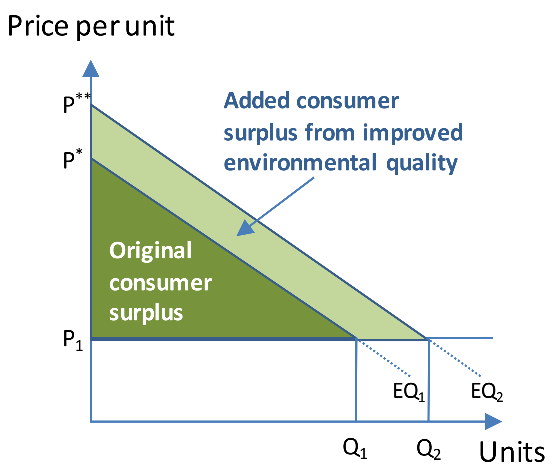


Figure 6.6: Environmental quality and consumer surplus (nonmarket consumer value). The two sloping lines represent environmental quality, EQ_1 showing the original and EQ_2 following improved environmental quality. The change in quantity at a given price, P_1, is positive but might equally plausibly be negative, thus reducing the consumer surplus. Source: Leeworthy and Wiley (1997. p 9).

Leeworthy and Wiley observed (1997, p 23) that although they explained the definitions of all major types of nonmarket economic values, they could only estimate the tourism and recreation uses of the natural resources of the Keys – then using the travel cost method but now apparently favoring the contingent valuation technique to identify people's willingness to pay, and willingness to accept a change. Also there were no attempts then to estimate the economic rents to producers (producer surplus) or the "passive use" values – bound to be important components as suggested by the Tortugas "policy analysis".

Nonmarket economic use values have a long tradition of use in benefit-cost analyses for public projects that either benefit or have adverse impacts on natural resources. Leeworthy and Wiley (1997) expected that the greatest benefits would result from applying the results in evaluations of the many public projects that would be required to fully implement the FKMNS management plan and the Monroe County Comprehensive Plan (focusing on a water quality plan). All these are basically project-orientated.

What follows below is a different perspective calling for different valuation criteria. It links to Peter Wiley's observation (2003) that every US citizen holds a claim to ownership of national resources, but it goes further in a different economic and political context.

6.5.4 ECOSYSTEM VALUATION AND THE POLITICS OF CLIMATE CHANGE

The GBR research reveals awareness of the long-term consequences of climate change, although it tackles the actual valuation analysis rather obliquely. Climate change is central to the GBR study, given that it compares a living reef system with a dead one. The research team acknowledges the irreversibility of the loss of any unique environmental natural capital resource (Oxford Economics, p 21).

"Likewise, it can be argued that even willingness to accept valuations does not take into account the non-substitutability of natural capital. By this reasoning, simply compensating people in financial terms of the loss of the GBR cannot provide a true "substitute" for its loss (as, say, an insurance payment for a damaged car might); it is an irreplaceable natural asset. In short, to the extent that the losses from bleaching are irreversible, the values in the current report may be considered conservative given the effective inadequacy of financial compensation.

Even if the full arguments about irreversibility and non-substitutability are not accepted, a partial acknowledgement of them suggests that, to the extent one can measure a consumer surplus associated with the GBR, it is questionable that this can simply be substituted for other activities in the event of bleaching. .. In short, the implications are that arguments about substitute consumption in the face of bleaching face considerable difficulties." (p 22)

The final sentence would ring more true if "face considerable difficulties" was changed to "are meaningless" – quite apart from the fact that the issue is climate change and not "substitute consumption in the face of bleaching". The authors reject (as this writer does) the suggestion by some economists that visitors to the reef might compensate by doing something else instead (go play in another yard?). But while the authors believe that the estimated compensation for the loss of a unique natural resource is "conservative", they give no inkling of how much they think the destruction of the unique resource (for which read GBR) is undervalued. It would certainly exceed the less than $100 per head that users claim they are willing to pay in the GBR analysis (Oxford Economics, p 21).

A $37.7 billion loss is "big" and might look politically impressive, but should it *really* be $50 billion, or $100 billion, or $500 billion? Based on what? The way forward would be to take a radically new look at the nonmarket values of preserving the ecosystems intact for this and coming generations across the planet (existence and bequest values). The assessment would replace what users say they would be willing to pay with what would be needed to preserve the ecosystems. It is safe to predict that these values would be much higher than those based on consumers' willingness to pay to preserve the ecosystems.

The valuation process will be difficult but the growing evidence that ecosystems are interdependent may provide a path. Stakeholders would be increasingly from outside the Florida Keys and living outside the United States, since climate change is global and ecosystems are more interconnected than previously realized. This would provide a global perspective within which to value the local ecosystems. The basis for the re-evaluation must be expert opinion unbiased by personal considerations, rather than users with no detailed knowledge of the intricacies and potential consequences of global climate change making an off-the-cuff assessment of what they would be willing to pay.

The recent report for French President Sarkozy on the shortcomings of GDP statistics agrees that climate change caused by increases in greenhouse gases is a special, truly global issue, going across national boundaries. "Physical indicators of this kind can only be identified with the help of the scientific community." (Stiglitz et al. 2009, pp 18-19, quoted in Hoegh-Guldberg 2010b.)

The valuation process could be based on an agreed set of projections of climate change ranging from global to local impact – perhaps a benign model such as scenario B1 as the base value and an economic growth model such as A1 as the basis for costing lack of action to prevent climate change. A series of workshops would give the best results, allowing participants to spark off each other and develop their concepts. Some of the concepts will be tricky and difficult to determine, and the procedures may have to differ from workshop to workshop to ensure that the full range of local and global views is represented.

It may be appropriate to make the frame of reference the "higher-order" Florida Keys network of interdependent ecosystems discussed in Section 3.3, embracing the whole of the sea- and land-based resources of the Keys. The reefs are important but not alone in the assessment, when we may be losing much more to climate change.

The preservation of ecosystems is accepted as a *sine qua non* in the fight against climate change, and coral reefs are at the forefront in this, and have been at least since the 1998 El Niño event. There is a quantum leap from individual willingness-to-pay measures to political advocacy. Governments, on scientific advice, are becoming convinced that climate change must be tackled politically, on a national and global basis. It therefore moves on to the stage of the political process including all the frustrations we are currently witnessing. It becomes science versus short-term commercial interests and climate change skeptics and deniers, and although connections remain between consumer attitudes and the political process in a democracy, we are on to an altogether different level in the decision-making process.

User assessments of how much they would be willing to pay to preserve a given ecosystem is relevant and good information in its own right, but we have gone on from there to the functioning of a democratic process, where it is not the personal wallet that is at stake, but how we allocate government funds and influence (or are influenced by) polluters and other vested interests. This is the real world situation where stakes are much higher than if a consumer is asked to set a level for his or her willingness to pay. The real world is exceedingly complex, and out of range of individual influence except through the ballot box.

There are important discount rate implications when changing from a project-based to a global climate change perspective of how ecosystems such as coral reefs should be evaluated. Ross Garnaut (2008) did suggest alternative rates of 2.6% and 1.3%, based partly on abstract economic arguments that the world is becoming richer and the marginal utility of extra income/benefit is therefore lower per individual in the future world. However, Garnaut, who was quoted as the source of the "preferred" discount rate of 2.65% in the GBR study, though he personally veered towards half that rate, also pointed to loss of amenities even in a richer world. The future user may not see all the extra wealth benefiting him or her, because much may go on items protecting against the impact of climate change, and life may not be as "happy" as the higher income might have us think. Finally, a hotter world would be both hellish and thwart the projected economic growth (Hoegh-Guldberg 2010b).

The consensus among climate change economists, including Ross Garnaut and Nicholas Stern, is that the discount rate should be low (Hoegh-Guldberg 2010c). It may be appropriate to adopt a social discount rate of 3% for project-based operation, as in NOAA's current evaluations, but in the interest of future generations a rate closer to 1%, or even lower, is more appropriate when assessing the impact of climate change on our grandchildren and further generations beyond.

6.6 SCENARIO IMPLICATIONS

The last section of each scenario story in Chapter 7 contains a narrative on the Florida Keys, a standard table containing eleven variables to be projected to 2100 (shown in Table 6.29), and a graph showing the expected paths for the main local variables. Because the scientific and statistical evidence is tending toward what was previously regarded as worst cases, the global numerical projections in Chapter 7 are based on halfway points between the "most likely" and "worst" cases. Even this may be not go far enough, and worst cases should be kept in mind at all times, especially global warming and sea-level rise reinforcing the risk of tipping points triggering further positive feedback effects.

The four global variables chosen for the numerical scenario projections are:

- Average global warming
- Sea-level rise
- Ocean acidification
- Change in global economic product.

These are accompanied by the following variables relating to the Florida Keys:

- Population, and population relative to 2010
- Coral cover, and coral cover relative to 2010 (proxy for marine-based tourism)
- Area remaining after inundation (determining population size)
- Value of area remaining after inundation
- Keys income relative to 2010, as a function of coral cover and value of area remaining.

Table 6.29: Schedule for numerical projections for each scenario

Scenario A1 (B1, A2, B2)	2010	2035	2050	2075	2100
Global temperature increase (^{o}C)					
Global sea-level rise (cm)					
Global ocean acidification (pH)					
Annual world GDP change					
Keys population					
Population relative to 2010					
Keys coral cover					
Coral cover relative to 2010					
Keys area remaining					
Value of Keys area remaining					
Keys income relative to 2010					

Naturally, there are major uncertainties in these projections. They are estimates that aim to be plausible but cannot at this stage be ultimately related in a formal statistical or mathematical model. No such model has yet been refined globally, or nationally for the United States. We have already discussed an attempt to estimate the present value of the Great Barrier Reef which must be branded unsuccessful for lack of reliable data (Section 6.5), and the considerable range of uncertainties around the "most likely" climate model estimates (Chapter 2).

Before coming to the four scenarios themselves, the final introductory section of Chapter 7 (7.1.5) discusses relationships between the chosen variables, including the connection between global warming and sea-level rise, which is crucial in the Keys context. It then defines a series of "algorithms" linking the local Keys variables as a basis for better definitions of the more important interrelationships.

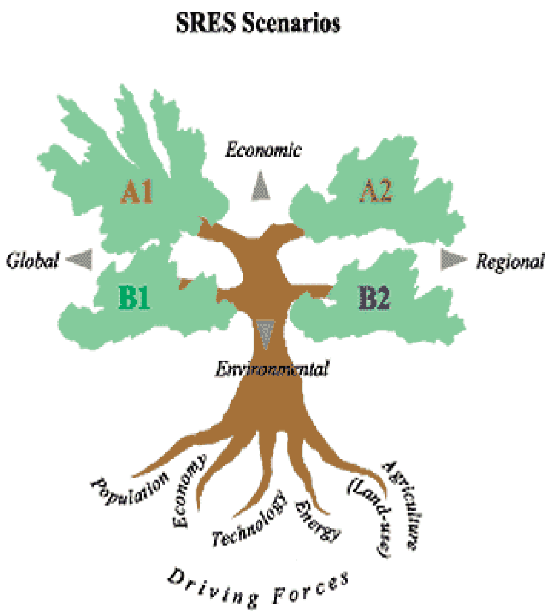
7 FOUR SCENARIOS

7.1 THE APPROACH

7.1.1 MODIFYING THE ORIGINAL SCENARIOS

The original global scenario storylines were sufficiently broad to remain *generally* plausible (Nakicenovic and Swart 2000: *Special Report on Emissions Scenarios* (SRES)). The narratives need some modifications, and as already noted in Chapter 2 (with reference to the detailed discussion in Hoegh-Guldberg 2010a) the expected impact of a given set of global climate change conditions has changed a great deal since the SRES scenarios were written in the 1990s.

Figure 7.1 schematically illustrates the SRES scenarios, showing how they build on the main driving forces of greenhouse gas emissions. Each scenario family is based on a common specification of the main driving forces. The four scenario families are illustrated in simple terms as branches of a two-dimensional tree. The two dimensions are global versus regional orientation (horizontal), and economic development versus environmental orientation (vertical). In reality, the scenarios are multi-dimensional, reflecting the numerous driving forces and assumptions needed to define any given scenario in a particular modeling approach.
Source: Nakicenovic and Swart, SRES (2000). Ref.: http://www.ipcc.ch/home_copyright.htm.



The four scenario stories were constructed along two dimensions: "economic development" versus "environmental" (vertical axis in Figure 7.1), and "global" versus "regional" (horizontal axis).

The former dimension seems reasonably unequivocal in terms of scenario development, but the latter gives rise to further thought. Exploring what each scenario means in a 2010 perspective, more than a decade after the stories were written, the realization dawned that the global-regional dimension was influenced by an assumption that globalization is "good" and regionalization is "bad". This is associated with the thinking of international institutions like the International Monetary Fund, the World Bank, and the World Trade Organization.

Though some of the views of these institutions are becoming more nuanced, as related in the next paragraph, a recent IMF publication could still state: "Based on experiences throughout the world, several basic principles seem to underpin greater prosperity. These include investment (particularly foreign direct investment), the spread of technology, strong institutions, sound macroeconomic policies, an educated workforce, and the existence of a market economy. Furthermore, a common denominator which appears to link nearly all high-growth countries together is their participation in, and integration with, the global economy." (Giovanni et al. 2008)

Yet, many international meetings on trade and finance have been marked by violent demonstrations. This has influenced the rhetoric and practices of international institutions, with the World Bank talking more about poverty and giving the countries it assists a proper decision-making role. Discussing the ways the World Bank in particular has changed its thinking, Joseph Stiglitz concluded in his book, *Globalization and Its Discontents*, that while globalization has brought huge benefits, not least in East Asia, major problems remain. "Globalization today is not working for many of the world's poor. It is not working for much of the environment. It is not working for the stability of the global economy. .. To some, there is an easy answer: Abandon globalization. That is neither feasible nor desirable. .. The problem is not with globalization, but with how it has been managed." (Stiglitz 2002, p 214)

This view is not contested here, but in the assessment of how applicable the four IPCC scenarios are twelve years or so after they were written, the one that may need most revision is B2, the environmentally orientated regionalized scenario story, which shared lowest economic growth in IPCC's Third Assessment Report with the other regionally based scenario, A2. This assessment seems too harsh in today's context, which places more importance on what is increasingly recognized as a misnomer: "non-economic" values such as sociocultural and ecological factors, and an analogous greater wariness of the conventional economic growth indicators. The low assessment of B2 (and burdening it with a rate of population growth to over 10 billion at the end of the century) was probably influenced by the unmodified previous ideas of the international institutions.

The drivers of scenarios can be any relevant sociocultural, technological, economic, ecological and political forces. For climate change, three main elements have modified the interpretation of these forces since the scenarios were first constructed:

1. There is much new evidence that climate change is happening faster than projected in IPCC's Fourth Assessment Report (Pachauri and Reisinger 2007). Scientists now advocate that the emissions of CO_2 and other greenhouse gases must be reduced to almost zero within the next decade. Leading climatologists like James Hansen of NASA have concluded that the atmospheric level of about 387 ppm CO_2 in 2008 may already be too high to avoid the risk of irreversible and dangerous climate change, and the target should be reduced to 350 ppm CO_2 or less (Hansen et al. 2008).

2. The understanding of positive feedback effects is now much improved, due to better climate models and actual observation. There is evidence of Arctic ice melting, ocean acidification, sea-level rise, and permafrost thaw. Such changes are nonlinear and may appear in leaps and bounds as "tipping points" are being reached.

3. No emissions scenario results in an exact impact on temperature and other climate change indicators. Because of complexities in the carbon cycle and other factors that are not fully quantified, there is always a range of variants, resulting in probabilities that the actual change will exceed (or fall short of) the "best" or "most likely" estimate. As temperatures rise, there is an increasing risk, according to Hansen and other climate

scientists, that large-scale nonlinear feedback effects will be triggered or accelerated. These effects could start at what would otherwise be a stabilization level of +3^{O}C or lower. The 2007 IPCC report noted that to prevent global warming from exceeding 2^{O}C by 2100 requires starting to reduce annual greenhouse gas emissions as early as 2015.

7.1.2 The climate change process

The scenarios must reflect the interactions between the various components of the climate change process. Figure 7.2 is from IPCC's Fourth Assessment Report.

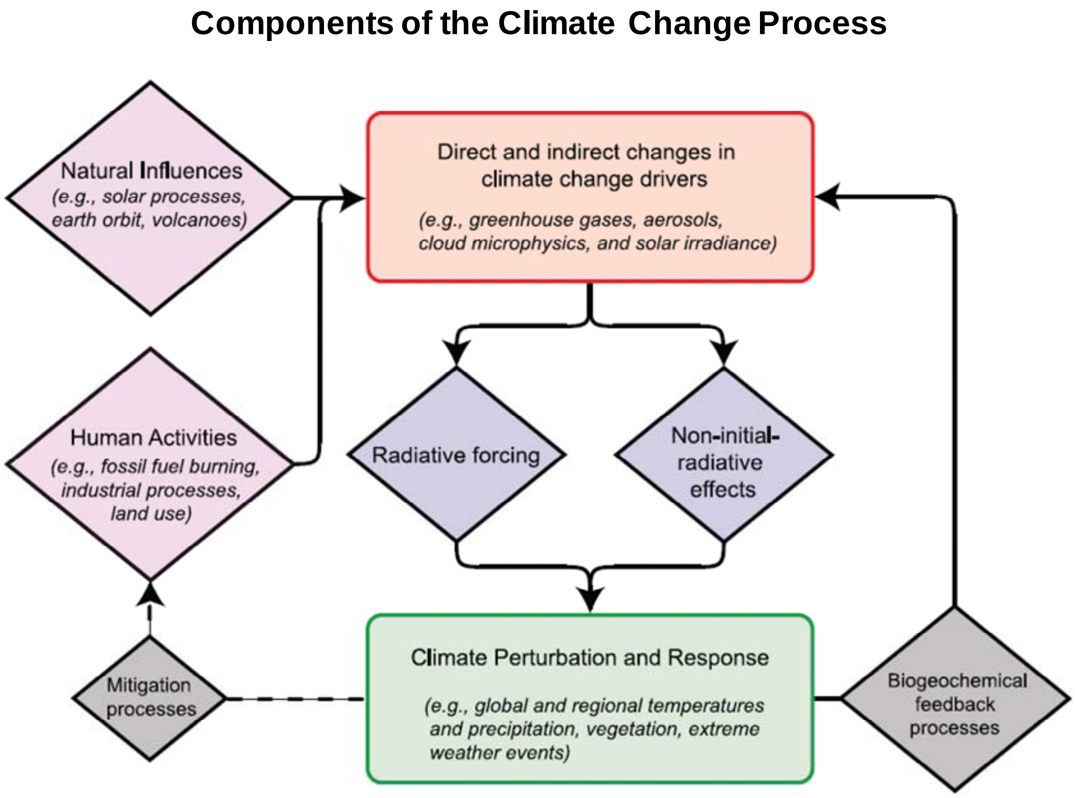


Figure 7.2: Linkages between radiative forcing and other aspects of climate change assessed by the IPCC. Human activities and natural processes, dominated by the former, cause direct and indirect changes in the drivers of climate change. These result in positive or negative changes in radiative forcing and cause some non-initial radiative effects, such as changes in evaporation. Radiative forcing and non-initial radiative effects lead to climate perturbations and responses. Coupling among biogeochemical processes leads to feedbacks from climate change to its drivers, for example the change in wetland emissions of CH_4 that may occur in a warmer climate. The potential approaches to mitigating climate change by altering human activities (dashed lines) are left out of the scenarios but are obviously vital factors and part of the policy recommendations in this report. Source: IPCC Working Group I report (Forster et al. 2007).

Radiative forcing compares the strength of different human-caused (anthropogenic) and natural agents (generated by its own internal dynamics) in causing climate change. It is defined as the change in net irradiance at the tropopause, measured in watt per square meter (Wm^{-2}) and designated ΔF. To provide a simple measure for quantifying and ranking the many different influences on climate change, it is related linearly to the global mean atmospheric surface temperature change ΔT_s via the equation $\Delta T_s = \lambda \Delta F$, where λ is the climate sensitivity (the change in global mean surface temperature that would result from a sustained doubling in atmospheric CO_2-e – carbon dioxide-equivalent greenhouse gases – from the pre-industrial level). The radiative forcing ΔF is positive if the global mean is rising, and negative if falling.

The contribution of greenhouse gases is dominated by carbon dioxide (CO_2), whose global mean in 2005 was 379 parts per million (compared with 260 ppm in 1750 and reaching 387 ppm in 2009). Its radiative forcing was +1.66 (±0.17) Wm^{-2}, where the uncertainty (±0.17) represents 95% probability limits. This represents three-quarters of total radiative forcing, which increased by 9% between 1995 and 2005, to +2.63 (±0.17) Wm^{-2}. The main remaining contributions, apart from soot particles comparable in impact to the methane emissions, were from methane (CH_4), with a global mean in 2005 of 1,774 parts per billion and radiative forcing at +0.48 (±0.05) Wm^{-2}, and nitrous oxide (N_2O), with a global mean in 2005 of 319 ppb and radiative forcing at +0.16 (±0.02) Wm^{-2}. The remaining greenhouse gases were mainly hydrochlorofluorocarbons (HCFCs), and chlorofluorocarbons (CFCs), which at the time of the Fourth Assessment Report were beginning to decline.

Paleoclimatic evidence shows that current atmospheric contents of CO_2 and CH_4 far exceed the natural range over the past 800,000 years according to Antarctic ice core data (Karl et al. 2009). Global sea levels, when Arctic summers were up to 5^{o}C warmer, were probably 4-6 m higher during the last interglacial period 125,000 years ago than is the case now. This and other paleoclimatic evidence makes it *virtually certain* that global temperatures during coming centuries will not be significantly influenced by naturally induced cooling. It is *very unlikely* that the Earth would naturally enter another ice age for at least 30,000 years (Jansen et al. 2007).

Emissions of carbon dioxide, methane, nitrous oxide and of reactive gases such as sulfur dioxide, nitrogen oxides, carbon monoxide and hydrocarbons, which lead to the formation of secondary pollutants including aerosol particles and tropospheric ozone, have increased substantially in response to human activities. As a result, biogeochemical cycles have been significantly disturbed. Nonlinear interactions between the climate and biogeochemical systems could amplify (positive feedbacks) or attenuate (negative feedbacks) the disturbances produced by human activities. (Denman et al. 2007, which is also the source of the next one-and-a-half paragraphs).

One example is the change in the land surface (vegetation, soils, water) resulting from human activities, which can affect regional climate through shifts in radiation, cloudiness and surface temperature. Another crucial coupling between biogeochemistry and radiative forcing is the carbon cycle between the atmosphere, oceans and land and coastal biosphere. The removal of CO_2 from the atmosphere involves a range of processes with different time scales. About 50% will be removed from the atmosphere within 30 years, a further 30% within a few centuries, but the remaining 20% will hang around for many millennia.

Absorptions of CO_2 into the ocean has lowered the pH (increased the acidity) from 8.2 by to 8.1 since 1750, thus reducing the calcification of shell-forming organisms and, in the long term, the dissolution of carbonate sediments. While the reduction in pH at first glance doesn't look much, the scale is exponential: each whole pH value, say 8, is 10 times more acidic than the next higher whole pH value. The already recorded increase in acidity indicates a 30% increase in the number of hydrogen ions (H^+) present in the water – a very significant increase in acidification. In a "business-as-usual" scenario the average ocean surface water pH is expected to decrease dramatically by a further 0.3-0.4 units (Doney et al. 2009, p 170).

Over the past decade since the Third Assessment Report was prepared, the confidence in the model estimates of future climate change has increased due to a range of advances. These include developments in the evaluation of climate feedbacks as well as improved model formulations, model climate simulations, and analytic methods (Randall et al. 2007).

In summary, the understanding of climate change has advanced significantly. The understanding of human-induced warming of the climate system was widespread by the time of the Fourth Assessment Report, and it was *extremely unlikely* that the global pattern of warming during the past half century can be explained without external forcing, and *very unlikely* that it was due to natural causes only. It was *likely* that there had been a substantial anthropogenic contribution to temperature increases in all continents except Antarctica since the middle of the 20^{th} century (Hegerl et al. 2007).

As this report notes repeatedly, events have kept pushing the findings of the Fourth Assessment Report towards or beyond the upper boundaries of its projections. The individual chapters quoted above from the Working Group I section of the Fourth Assessment Report give further detail such as the anthropogenic influence on other parts of the climate system including Arctic sea-ice content and glacial retreat, according to the knowledge accumulated by early 2007.

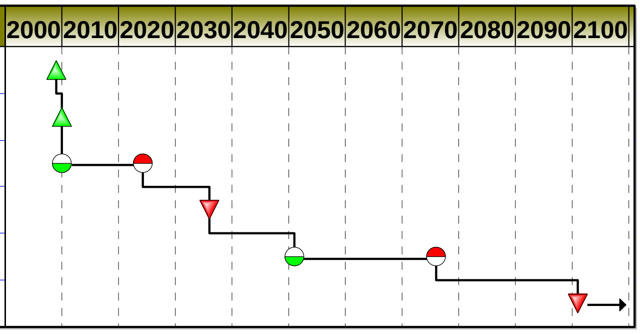
7.1.3 GLOBAL SCENARIO STORIES

All storylines are reproduced verbatim from the SRES report (Nakicenovic and Swart 2001), apart from omitting most of the references to other scenarios given in the source. These examples are interesting but detailed references can be identified in the source document.

The storyline is followed by a section on its current plausibility ("Would the scenario story have been written this way in 2010?"). The evaluation takes into account that scenarios, to be useful, need a sufficiently wide span to cover all plausible worlds. Some aspects of the scenarios may appear extreme, but the issue is whether they remain inside the realm of what could plausibly happen if no corrective action is taken. The subsequent section then asks whether modifications are needed in light of the review of changing physical, economic and technological factors (Hoegh-Guldberg 2010a,b,c,d), which is an advance on previous scenario analysis.

Figure 7.3: Scenario milestones

STAGE	Year
Update SRES scenarios	2009
Scenarios start	2010
Path towards main scenario story	2020s
"Near term" milestone	2035
Intermediate long-term milestones	2050/75
Final milestone and further outlook	2100+



A brief pathway for each scenario is then outlined from 2010 to the time when the storyline kicks in, say, by the mid to late 2020s (Figure 7.3). The global path is outlined to 2100 on the assumption that no attempt is made to mitigate the impact of climate change.

As part of the description of the global path and the implications for the Florida Keys, a "near-term" milestone is set for 2035 as recommended by Moss et al. (2008), who are preparing the scenario principles for IPCC's Fifth Assessment Report. The authors say that key issues for the "near-term" analysis will eventually include identifying immediate risks, developing corresponding adaptive capacity, reducing vulnerability, making efficient investments to cope with climate change, developing low-emission technologies and energy conservation, and preserving and improving sinks (all covered in the review of technologies, Hoegh-Guldberg 2010d).

The penultimate milestone for the storylines is the "long-term" view of 2100 (supplemented in Figure 7.3 by intermediate markers in 2050 and 2075). In the long-term view, Moss et al. (2008) note that the policy focus shifts towards evaluating climate targets to avoid risks from climate change impacts, improving the understanding of risks of major geophysical and biogeochemical change and feedback effects, and adopting strategies for adaptation, mitigation, and development that are robust over the long term to remaining uncertainties. Scenarios of different rates and magnitudes of climate change will provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

While the scenarios are presented in this chapter as they would play out without remedial action, the points made in connection with the "near-term" and "long-term" views are useful guidelines for the policy recommendations in Chapter 8.

The 2100 milestone is called "penultimate" to leave space for a quick view into the future from the end of the century focusing on matters such as coral cover and sea levels, human population, economic and social trends, and wealth distributions across the planet. The idea of a 'view beyond' follows recent practice, including a perspective on reef development in the Coral Triangle between Indonesia, the Philippines and the Solomon Islands over the next three centuries (Hoegh-Guldberg et al. 2009). Stern (2009) also notes that some stabilization paths may continue well into the 22nd century.

7.1.4 Scenario stories for the United States

Next, the focus in each scenario section (7.2 to 7.5 below) is narrowed from global to local, zooming in on the Florida Keys after a brief sketch of a future United States – kept fairly unspecific because Florida and the Keys themselves are microcosms of America, albeit microcosms at particularly high risk. It is based on Cullen Murphy's book *A New Rome* (Murphy 2007), which ends with an outline of three scenarios (see addendum at the end of Hoegh-Guldberg 2010a). He contrasts these with what he calls, in line with his Roman theme, "The Titus Livius hundred-year workout plan". This environmentally and sociologically friendly scenario has four components:

1. *Instill an appreciation of the wider world*, helped by immigration and the influx of foreign students. There is no substitute for fluency in another language. "Every educated person in the Roman Empire spoke at least two languages, and so did the strivers in the, uh,

immigrant hordes. Americans have their priorities backward. They worry needlessly about the second part: whether the immigrants will ever learn English. They should be worrying about the second part: whether the elites will ever speak anything else."

2. *Rely on government proudly for the big things it can do well*, rather than treating it as a necessary evil. Governments act as a counterforce to inequality, and can be held accountable in ways the private sector cannot. "It takes some imagination to see how corrosive privatized government will prove to be many decades down the road – and that's another thing: start thinking in centuries."

3. *Fortify the institutions that promote assimilation*. America already has a powerfully absorptive and transformational domestic culture, but it needs to be reinforced rather than undermined. "In Massachusetts recently a debate broke out over whether the children of illegal aliens should be allowed to pay the low "in-state" rate at public colleges and universities. The answer should have been yes. The answer to public schools and public health services for immigrants should always be yes – these do more, with less, than any fence can accomplish."

4. *Take some weight off the military*, eliminating some of the things we need an army for. Rome turned into a state whose entire purpose was military. "America is still free to make choices. It can let regional powers shoulder more of the burden. One unilateral decision above all would buy a lot of breathing room, and ought to be made regardless: to adopt a long-range energy policy based as much as possible on renewable resources, allowing us to pull away, eventually, from military oversight of the entire Middle East." (Murphy called this a hundred-year project – "Rome wasn't built in a day". But we would have to build a long-range energy policy in much less than a century.)

7.1.5 FROM GLOBAL TO LOCAL SCENARIOS

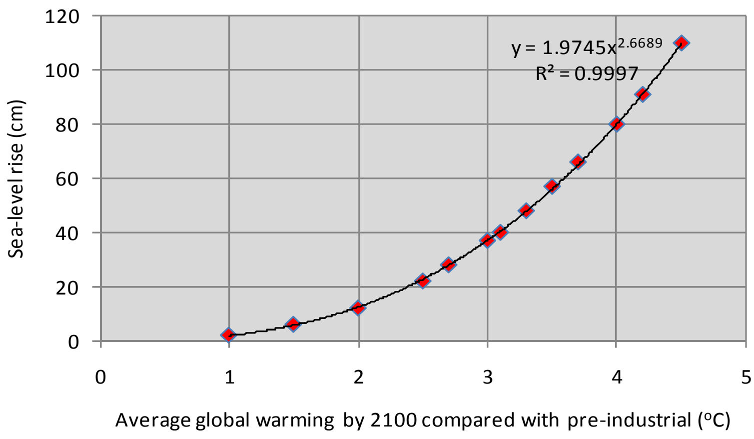
One major problem when progressing to the local level is to retain a quantitative framework, for example by identifying "algorithms" to link the various variables. The purpose is to lend credence to the local projections, to the extent that plausible interrelationships can be found.

The greatest change since the publication of IPCC's *Fourth Assessment Report* (Pachauri and Reisinger 2007) concerns the impact on sea levels under global warming, which is of vital significance to the Florida Keys for obvious reasons. In the B1 scenario, the median global temperature rise was 1.8^{O}C and the mid-point sea-level rise 28 cm. In the worst-case A2 and A1FI scenarios, the global mean temperature was calculated to increase by 3.4^{O}C and 4.0^{O}C, respectively, and the mid-point sea-level rise was 37 and 43 cm, respectively. The difference between the best- and worst-case scenarios is expected to be much wider today, as illustrated by Chris Bergh's investigation of the impact of sea-level rise on the Florida Keys, which is a key source for the current section and mentioned in several other connections in this report including the policy recommendations in Chapter 8 (Bergh 2009).

This section discusses the relationships between the global and local factors shown in Table 6.29 at the end of the previous chapter. The four global factors are interrelated: global warming, sea level, ocean acidity, and world GDP.

The global temperature increase is the main external or "exogenous" variable, defined by the IPCC in relation to each scenario and discussed in detail by Hoegh-Guldberg (2010a). Its relationship to the world economy is explained in Hoegh-Guldberg (2010b), including the constraints on growth if global warming accelerates as projected. The global ocean chemistry measured by pH has been projected to change from 8.1 to 7.7 in a worst-case scenario (Doney et al. 2009). This has been adopted as a guide to the economically orientated scenarios, A1 and A2, with lesser changes projected for the B1 and B2 cases.

Figure 7.4: Sea-level rise versus global warming



The crucial link in the Florida Keys context, however, is between global warming and sea-level rise. Adopting the more pessimistic views emerging since 2007, Figure 7.4 suggests that the link can be described by a power curve. Estimated value pairs include 12 cm sea-level rise at 2°C warming, 37 cm at 3°C, 57 cm at 3.5°C, 80 cm at 4°C, and 110 cm at 4.5°C. These values are generally in tune with recent literature, including the assumptions Bergh (2009) made for sea-level rise in the Florida Keys, and comparison of global warming trends and sea-level change over the 21st century (Rahmstorf 2007).

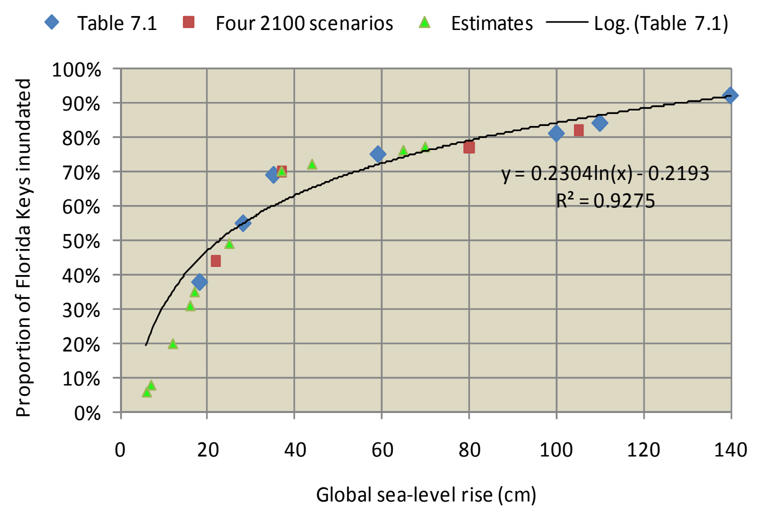
Table 7.1: Projected areas and values of Florida Keys land at risk

Global sea-level rise	At risk (area) 000 acres	At risk (area) Relative	At risk (value) $ billion	At risk (value) Relative
18 cm	58.8	38%	11.0	26%
28 cm	*85.0*	*55%*	*15.2*	*35%*
35 cm	106.0	69%	18.7	43%
59 cm	115.0	75%	21.9	51%
100 cm	124.0	81%	26.7	62%
110 cm	*129.0*	*84%*	*29.0*	*67%*
140 cm	142.0	92%	35.1	82%
	Total area in 2008 (000 acres)		Total value in 2008 ($ billion)	
Original totals	154.0	0%	43.0	0%

Source: Bergh (2009), Table 1, p 25 (28 cm and 110 cm interpolated)

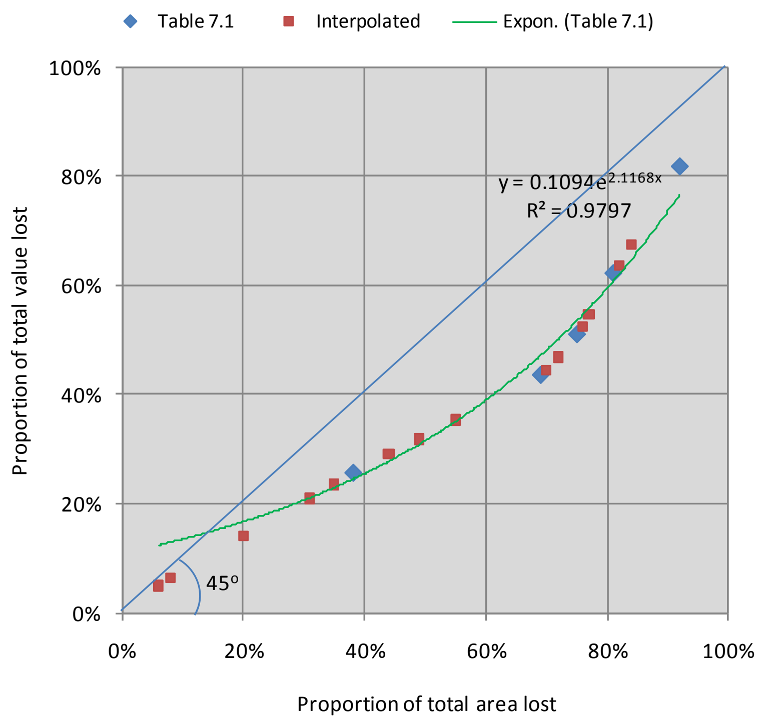
This provides the key to the relationship between global sea-level rise and the degree of inundation expected in the Florida Keys. Keys-wide data are shown in Table 7.1, derived from the main table on p 25 of Bergh's projections for the Florida Keys (2009). Considering first the relationship between global sea-level rise and the area at risk in the Florida Keys, the latter increases from 38% of the total Keys area at the *most optimistic* B1 scenario (rather than the *most likely* B1 scenario), which has the global sea-level increase at 18 cm by the end of the century. At the "extreme Rahmstorf projection" of a 140 cm increase in the global sea level, 92% of the Keys area is considered at risk. The values from Table 7.1 are plotted as blue diamonds in Figure 7.5, which also shows the four estimated end points for each scenario (shown as red squares), and various interpolated and extrapolated estimates (green triangles). The correlations are approximated by a logarithmic fit but the data clearly fall into two groups:

Figure 7.5: Global sea-level rise and Keys area covered



- Inundation of the Keys is expected to proceed along a more or less straight line (to 70%) as the global sea-level rise reaches about 35 cm.
- It then proceeds at a much slower pace towards 92%, reached at the "extreme Rahmstorf projection" of 140 cm global sea-level rise.

Figure 7.6: Keys land loss by area versus value



These features would be associated with the particular elevation patterns of the Keys as revealed by Chris Bergh's analysis. The preponderance of very low-lying areas and a minority of higher areas more resistant to flooding would help explain the pattern.

Bergh's research also shows that the relative physical land loss exceeds the relative loss of the value of the land. The relationship between loss of land and loss of value is best described by an exponential curve (Figure 7.6). Again, the evidence comes from the main table in Bergh (2009, p 25). Compared with the 45^{O} line from the origin of the graph which would equate the proportions of area and value loss, the estimated loss in value since 2010 at, say, 40%, is more than 20 percentage points below the proportion of total loss of area (60%), before the gap starts to narrow between the two measures, as the exponential curve trends back towards the 45^{O} line again.

Table 7.1 supplement: Lower, Middle and Upper Keys

Lower Keys

Global sea-level rise	At risk (area)		At risk (value)	
	000 acres	Relative	$ billion	Relative
18 cm	11.0	18%	2.6	12%
35 cm	49.4	82%	8.8	42%
59 cm	54.4	90%	11.0	53%
100 cm	56.3	93%	13.0	62%
140 cm	58.0	96%	15.8	76%
Lower Keys	000 acres		$ billion	
2008	60.5	0%	20.9	0%

Middle Keys

Global sea-level rise	At risk (area)		At risk (value)	
	000 acres	Relative	$ billion	Relative
18 cm	4.4	25%	0.8	12%
35 cm	9.5	54%	1.9	29%
59 cm	11.2	64%	2.6	41%
100 cm	12.6	72%	3.5	55%
140 cm	17.3	99%	6.0	94%
Middle Keys	000 acres		$ billion	
2008	17.5	0%	6.4	0%

Upper Keys

Global sea-level rise	At risk (area)		At risk (value)	
	000 acres	Relative	$ billion	Relative
18 cm	43.3	57%	7.6	48%
35 cm	47.5	62%	8.0	51%
59 cm	49.6	65%	8.3	53%
100 cm	55.6	73%	10.1	64%
140 cm	67.1	88%	13.2	84%
Upper Keys	000 acres		$ billion	
2008	76.1	0%	15.7	0%

The overall results in Table 7.1 do not apply universally across the Keys. The main table in Bergh (2009, p 25) displays separate findings for the three main parts of the Florida Keys as shown in the supplement to Table 7.1 to the left.

The Lower Keys (60,500 acres) before any land loss account for 39% of the 154,000 acres of the Florida Keys, compared with 11% in the Middle Keys and the remaining half in the Upper Keys. In value terms, however, the Lower Keys in 2008 accounted for 49% of the total compared with 15% for the Middle Keys and 36% in the Upper Keys.

If the global sea level rose by 35 cm, which according to Figure 7.5 is close to the point where rapid inundation in response to global sea-level rise gives way to a slower process, 82% of the Lower Keys would be at risk, compared with 54% of the Middle Keys, and 62% of the Upper Keys. In value terms, the proportions at risk at 35 cm global sea-level rise would be 42%, 29%, and 51%, respectively.

There are clearly quite large differences between the estimated rates of inundation from area to area and the estimated value of the areas at risk. The Middle and Upper Keys, for example, are relatively less at risk up to what is regarded to be beyond the worst-case scenario in this report (but still conceivable), a 100 cm global sea-level rise. At this level, 72-73% of the land in these areas would be at risk, compared with 93% in the Lower Keys. If a 140 cm rise happened, however, little would remain of the Middle Keys, compared with 4% of the Lower Keys and as much as 12% of the Upper Keys.

The relationship with values, however, is more complex. Figure 7.6 showed that in the Keys as a whole, the maximum difference between land loss and value loss increases to over 20 percentage points with land loss at over 60% and value loss below 40%. In the Lower Keys, the area at risk at 35 cm global sea-level rise is 82% of the 2010 level but only 42% in value terms, a difference of fully 40 percentage points. Even in the extreme worst case, a global sea-level rise of 140 cm and 96% of the total Lower Keys area lost (4% remaining), 24% of the total initial value would remain. Key West is evidently expected to remain an important asset, even in the worst of changing climates. The same clearly cannot be said about the rest of the Lower Keys.

Table 7.2: Population and income implications?

Year	Scenario			
	A1	B1	A2	B2
A: Population declines in proportion to area (thousand)				
2010	72.0	72.0	72.0	72.0
2035	57.6	67.7	49.7	66.2
2050	21.6	57.6	20.2	49.7
2075	18.0	46.8	16.6	36.7
2100	16.6	40.3	13.0	21.6
B: Population relative to 2010				
2010	100.0%	100.0%	100.0%	100.0%
2035	80.0%	94.0%	69.0%	92.0%
2050	30.0%	80.0%	28.0%	69.0%
2075	25.0%	65.0%	23.0%	51.0%
2100	23.0%	56.0%	18.0%	30.0%
C: Gross income declines in proportion to remaining value				
2010	100.0%	100.0%	100.0%	100.0%
2035	86.0%	95.0%	79.0%	93.5%
2050	55.6%	86.0%	53.2%	79.0%
2075	49.1%	76.5%	45.3%	68.2%
2100	45.3%	71.0%	36.5%	55.6%
D: Index of wealth per person from the above				
2010	100.0	100.0	100.0	100.0
2035	107.5	101.1	114.5	101.6
2050	185.2	107.5	190.0	114.5
2075	196.4	117.7	197.1	133.6
2100	197.0	126.7	202.5	185.2

Source: See text

In the Middle Keys, the gap between proportion of initial area at risk and the corresponding proportion of value at risk widens to 25 percentage points at 35 cm global sea-level rise, while the difference is only 11-12 percentage points in the Upper Keys, where it occurs between 35 and 59 cm global sea-level rise. The Upper Keys, however, would still retain the largest proportion of original land under the extreme worst-case scenario of 140 cm sea-level rise (12%, compared with 4% for the Lower Keys and only 1% for the Middle Keys).

One final set of relationships remains to be analyzed (Table 7.2). If we assume that population declines in proportion to the area lost, the drop is smallest in the B1 scenario (44%) and largest in scenarios A1 and A2 (77% and 82%, respectively). The environmentally friendly regional scenario B2 also dips quite strongly in the final quarter of the century if we apply this model.

The one-to-one ratio between declining population and land area makes most sense in the context of carrying capacity but not between gross income and remaining land values. It works as a useful illustration if carrying capacity is already stretched to the limit, which seems to be a sensible working hypothesis.

There is less justification for applying a rule that gross income declines in proportion to the remaining value of the Keys land, which we have seen shows a smaller drop than the land area. Panel C of Table 7.2 suggests that B1 shows the smallest reduction in gross income under this assumption, followed by B2, A1 and A2. The model proves to be of doubtful validity when we apply the final logic of constructing an index of per capita wealth based on Panels B and C of Table 7.2. Panel D suggests that the index doubles for both the economic scenarios, A1 and A2, with B2 not far behind. Scenario B1 lags far behind these other indices, with a 26% increase by the end of the century.

In conclusion, while the previous “algorithms” developed in this section make reasonable sense, the assumptions underlying Table 7.2 must be carefully considered, especially the relationship between value loss and total income or wealth in the Keys.

One local indicator that has not yet been mentioned in this section is coral cover. Although nature-based tourism declined relative to history-based tourism between 1995-96 and 2007-08, it is considered to be of continuing importance for a range of economic and scientific reasons. Scientists generally agree that the coral reefs would suffer beyond survival in a “business-as-usual” scenario, which suggests that the cover would disappear in the A1 and A2 scenarios.

It is rational to assume, however, that the emphasis on reef resilience initiated by the TNC, the FKNMS, the State of Florida, Monroe County, community groups and others would bear fruit – coral cover in the B1 and B2 scenarios is therefore assumed to remain, though at lower than current levels. We have found no “algorithms” to estimate what levels would be reasonable, and the projected levels are not sacrosanct. But the continued existence of a significant part of the reef is important in itself, whether the ultimate cover is 3%, 4% or 5%. The assumption made here is that the cover is reduced to 3.5% in scenario B1, and to 3.0% in B2 (compared with 6,4% currently).

In conclusion, the lack of additional carrying capacity imposes such a strain that is seems plausible to assume that the local population will decline in proportion with the land loss as inundation occurs. This is the assumption adopted for the population projections under each scenario.

This leaves the dilemma of how to estimate local income trends from insufficient data. Two considerations provide guidance:

- Assuming that the projections of residual land values are realistic (dominated by Key West), it is plausible that an increasing proportion of these values will benefit people, corporations and institutions who are not residents of the Florida Keys. While it is impossible to put a figure on this proportion, this will inevitably reduce the income and wealth of local residents from the potential suggested by Table 7.2.
- Coral cover can be seen as a partial proxy for marine-based tourism value, especially since other indicators such as fish stock have also declined. In addition, a relatively vigorous tourist industry may be instrumental in retaining a higher share of the real-estate wealth in the Keys, though this would be difficult to measure.

We have concluded that local income or wealth will be governed by two factors: the value of remaining land in Key West and the rest of the Florida Keys, and the remaining coral cover, acting as a proxy for marine-based tourism strength. With no further evidence on hand, a simple average of the two factors is used to derive an illustrative (rather than powerful) "algorithm" for determining the trend in total income or wealth in the Keys.

The relationships will be taken into account for possible inclusion in the local Keys scenario stories (Sections 7.2.7, 7.3.7, 7.4.7, and 7.5.7).

7.2 Scenario A1: Global economic focus

7.2.1 The IPCC storyline

The A1 storyline is a case of rapid and successful economic development, in which regional average income per capita converge – current distinctions between "poor" and "rich" countries eventually dissolve. The primary dynamics are:

- Strong commitment to market-based solutions.
- High savings and commitment to education at the household level.
- High rates of investment and innovation in education, technology, and institutions at the national and international levels.
- International mobility of people, ideas, and technology.

The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion.

This may be the type of scenario best represented in recent literature. Such scenarios are dominated by an American or European entrepreneurial, progress-oriented perspective in which technology, especially communication technology, plays a central role. Various scenarios designed in 1995 share features with A1. They emphasize market-oriented solutions, high consumption of both tangible and intangible commodities, advanced technology, and intensive mobility and communication. In some examples of this type of scenario, high economic growth leads to shifts of economic power from traditional core countries to the current economic "periphery”. The [previous] IPCC Scenarios IS92a and IS92e are well-known examples of futures with high levels of economic growth. IIASA [International Institute for Applied Systems Analysis] and [the] World Energy Council jointly developed three high growth scenarios that share assumptions on rapid technological progress, liberalized trade markets, and rising income levels.

In the A1 scenario family, demographic and economic trends are closely linked, as affluence is correlated with long life and small families (low mortality and low fertility). Global population grows to some nine billion by 2050 and declines to about seven billion by 2100. The average age increases, with the needs of retired people met mainly through their accumulated savings in private pension systems.

The global economy expands at an average annual rate of about 3% to 2100, reaching around US$550 trillion (expressed in 1990 dollars). This is approximately the same as average global growth since 1850, although the conditions that lead to this global growth in productivity and per capita incomes in the scenario are unparalleled in history. Global average income per capita reaches about US$21,000 by 2050. While the high average level of income per capita contributes to a great improvement in the overall health and social conditions of the majority of people, this world is not necessarily devoid of problems. In particular, many communities could face some of the problems of social exclusion encountered in the wealthiest countries during the 20th century, and in many places income growth could produce increased pressure on the global commons.

Energy and mineral resources are abundant in this scenario family because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves. Final energy intensity (energy use per unit of GDP) decreases at an average annual rate of 1.3%. Environmental amenities are valued and rapid technological progress "frees" natural resources currently devoted to provision of human needs for other purposes. The concept of environmental quality changes in this storyline from the current emphasis on "conservation" of nature to active "management" of natural and environmental services, which increases ecological resilience.

With the rapid increase in income, dietary patterns shift initially toward increased consumption of meat and dairy products, but may decrease subsequently with increasing emphasis on the health of an aging society. High incomes also translate into high car ownership, sprawling suburbia, and dense transport networks, nationally and internationally.

Several scenario groups considered in the A1 scenario family reflect uncertainty in the development of energy sources and conversion technologies in this rapidly changing world. Some scenario groups evolve along the carbon-intensive energy path consistent with the current development strategy of countries with abundant domestic coal resources. Other scenario groups intensify the dependence on (unconventional) oil and (in the longer-run) natural-gas resources. [These groups were merged into the fossil-intensive A1FI scenario.] A third group envisages a stronger shift toward renewable energy sources and conceivably also toward nuclear energy [A1T]. A fourth group (which includes the A1B marker scenario) assumes a balanced mix of technologies and supply sources, with technology improvements and resource assumptions such that no single source of energy is overly dominant. The implications of these alternative development paths for future greenhouse gas emissions are challenging: the emissions vary from the carbon-intensive to decarbonization paths by at least as much as the variation of all the other driving forces across the other SRES scenarios.

7.2.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

Following the response to this question, Section 7.2.3 will examine possible physical influences on the A1 scenario, from the analysis in Hoegh-Guldberg (2010a,b,c,d).

Scenarios should range to the limits of the plausible – bearing in mind that all four scenarios are considered equally likely to occur and would run their course in the absence of any mitigating action. There may nevertheless have been a shift in perceptions compared with the early to mid 1990s when the scenarios were written.

The broadening range of developing countries growing into greater economic prominence represents a significant change. The term 'BRIC' was applied in 2001 to Brazil, Russia, India, and China (two other nations, Mexico and South Korea, were considered more developed). *The Economist* has called the BRIC countries the 'trillion-dollar club' since they are the only nations outside OECD whose GDP exceed that amount (*The Economist* 2010a – the next in line, Mexico and South Korea, weighed in at about $800 billion in 2009, like OECD member Australia at $900 billion approaching the trillion-dollar mark). A new term, BIICS, has been coined to comprise Brazil, China, India, Indonesia, and South Africa (OECD 2010). Russia was excluded from this group only because of its status as an accession candidate for OECD membership (together with Chile, Estonia, Israel, and Slovenia).

By way of background, the main critics of the IPCC scenarios, with the largest potential effect on A1, were Castles and Henderson (2003), because incomes were compared using market exchange rates (MER) rather than a purchasing-power-parity (PPP) basis which compares income levels based on how much of a country's currency would buy what one dollar would buy in the United States. There is less difference between national per capita incomes using PPP than using MER, so allegedly less catching up to do by poorer countries.

Castles' and Henderson's criticism was refuted (Nakicenovic et al. 2003), and the debate appears to be closed. Our own comments follow on what may have changed by 2010:

- The assumption that incomes would converge between all countries has always seemed to verge on heroic, especially as far as the countries defined as least-developed are concerned, two-thirds of them in Sub-Saharan Africa, and the remainder ranging from Haiti to Afghanistan. The global economic growth projections are also very high, accelerating to 4.7% per annum through the 2020s before slowing towards 1.7% pa between 2080 and 2100 when the global population is falling (Hoegh-Guldberg 2010b, Table 2). The IPCC's A1 growth projections, in all three variants, are the highest of all scenarios.
- Climate policy may be changing, with less emphasis on penalizing schemes including cap-and-trade and more – or at least a joint emphasis – on a straight carbon tax and incentives, as expressed in a study led by Gwyn Prins of the London School of Economics (Prins et al. 2009) and followed up after the relative failure of climate change policy to proceed in Copenhagen in December 2009 (Prins et al. 2010). Although the scenario rules don't allow climate policy to be changed during the period of the scenario, the

different policy directions should be taken into account in the initial definition of each scenario to highlight their divergent paths.

- The America-centric or Eurocentric bias that the narrative admits to would be less acceptable today, as we witness the dramatic ascendancy of very different economies and cultures, led by China and India. It remains plausible to assume that these countries will participate in a globalized economic growth society, but the description of their societal patterns, and what these mean, would need to be more nuanced than expressed in the current narrative. For example, China's efforts in the areas of mitigation motivated by its fragile environment (massive railroad development, development of solar and other new technologies) have to be judged against the impact of its equally massive development of coal-fired energy projects, hoping without certainty that carbon capture and storage (CCS) technology will become cost-effective in time. Again, the outcome would differ markedly between scenarios.

- As the concern about ecosystems and possible domino effects is increasing, the assumed change from the current emphasis on "conservation" to active "management" of natural and environmental services needs rethinking and rephrasing. It is doubtful that the "management" envisaged by the 1990s scenario builders would still be considered likely to increase overall ecological resilience, given the growing understanding of how ecosystems are interconnected and how positive feedback effects develop from tipping points in the climate models.

Other points might be added, and a globalized growth scenario would have to start from much more detailed analysis of the current situation than can be done here – it is impossible to write a whole new storyline within the confines of this project. However, looking at the storyline as distinct from the observed greater threat from climate change, economic management becoming more complex, and the development of technology over the past decade, there can be no dispute that the scenarios must include a high growth version based on faith in technology as the great fixer, while relegating environmental policies, and sociocultural policies as well, to lesser roles.

7.2.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

The scientific assessment of climate change – shared by leading climate change economists – has become progressively more pessimistic over the past decade, reaching a position where global average warming above $2^{O}C$ is considered dangerous, and atmospheric CO_2 should be reduced from present levels to 350 ppm or less. This is the story in Hoegh-Guldberg (2010a).

According to the Fourth Assessment Report (Hoegh-Guldberg 2010b, Table 2), the most likely temperature change in the marker scenario of "balanced" fossil and renewable fuel technologies (including nuclear) is $2.8^{O}C$, and the worst case within the range of projections $4.4^{O}C$. In the fossil-intensive variant, A1FI, the most likely outcome is $4^{O}C$ and the worst case $6.4^{O}C$. If renewables should start to dominate energy supplies in the "A1T" scenario variant, the most likely case is $2.4^{O}C$ and the worst case $3.8^{O}C$. The then assumed CO_2 levels in 2100 were 710 ppm (A1B), 964 ppm (A1FI), and 578 ppm (A1T).

Ignoring that projections since 2007 would generate higher average temperature changes for the A1 scenarios (more so than for other scenarios, especially B1), the economic growth model based on average global warming (Hoegh-Guldberg 2010b, Figure 5) suggests that in the "most likely" case the balanced technology marker scenario A1B would show uninterrupted growth through the century, but the fossil-intensive scenario A1FI would turn negative from 2080. In the worst case based on the Fourth Assessment Report, A1FI turns down from the 2050s, the marker scenario A1B from 2080, and even the A1T scenario that envisages a change to renewable and nuclear energy sources starts to decline from 2090. The political consequences in a world based on a strong growth philosophy entering constant economic decline are unimaginable – the current global financial crisis is a pinprick in comparison.

Hoegh-Guldberg (2010a) contains many warnings that worst cases have tended to become mainstream, from Weitzman's "fat tail" distribution giving more weight to extreme outcomes (2009), and Garnaut's (2008) observation that some severe and damaging shocks that were once near the edges of the distributions are now near the middle, to the unequivocal warning by Richardson et al. (2009) at the Copenhagen scientists' meeting in March 2009.

One feature of the A1 scenarios may be that the laissez-faire economic policies that allegedly led the world into trouble in 2008 (see Hoegh-Guldberg 2010c) will be perpetuated, causing continued corporate and financial sector growth fixation and predatory behavior. The final question is whether the strong faith in technological solutions underpinning these scenarios would be justified. At best, this may be a race against time: will the technologies be able to make all countries take a quantum leap, with the right mix to assist the weaker nations as well as the right mix to protect against the worst excesses of climate change?

The risks of following such a course are great. The one possible positive factor is the global population projection: while inevitably going to nine billion by 2050 it will then decline to seven billion by the end of the century, with virtually all countries eventually contributing to the decline since we have already witnessed an general decline in fertility rates (children per woman): The world average fell from 4.47 in 1970-75 to 2.55 in 2005-10 and is expected to decline further to 2.02 in 2045-50 according to the United Nations medium 2006 projection. In 1970-75, 143 of 195 countries (73%) showed a total fertility rate of 3 or more. This had fallen to 71 countries (36%) by 2005-10 and is projected to fall to only seven countries (less than 4%) by 2045-50.

7.2.4 Linking the present to the storyline

The A1 scenarios, especially the fossil-intensive variant, have been seen as closest to the "business-as-usual" scenario which economists and scientists alike denounce as a disastrous long-term path. Other scenarios, however, are equally likely and possible, at least in principle (B2 now seems more outdated than the other scenarios, and would be more favorably viewed today). Whatever is made out of the slowness and setbacks of the current political process, environmental policies and concerns for climate change have gained prominence over the past several years, significant business opportunities have emerged, and the foundation has been strengthened for a plausible global scenario of the "B1" variety. It is also possible that the trend towards globalization of the past few decades – never fully accepted as the only possible world philosophy despite past advocacy from international organizations – may be replaced by a more regionalized world, as in A2 and B2.

That said, the path towards a steady-state A1 type scenario is relatively close to "business-as-usual", even uncomfortably so. While the realization of this might act as a wake-up call which could cause a more decisive switch to an environmentally protective B1 alternative, the rules of scenario planning for now are that each is played out without mitigation.

An introduction to the A1 scenario story written for this project in early 2009 has proved substantially correct and can now be the lead-in to all four scenario stories:

Despite increasing attention to climate change in the lead-up to the Conference of the Parties in Copenhagen in December 2009 (COP-15), climate change deniers and enormous vested business interests prevail. The financial crisis deprives the world of fresh American leadership against climate change, and resistance from Congress cripples the Administration's moves to address the issue of climate change in matters such as effective carbon cap-and-trade schemes and assistance to developing countries to reduce the rise in greenhouse gas emissions and taking a bold initiative in Copenhagen in December.

The main casualty, not anticipated in early 2009, may have been universal cap-and-trade schemes. Apart from the reference in Section 7.2.2 to the work of Glyn Prins and his colleagues (2009, 2010), this is discussed in Hoegh-Guldberg (2010c) under the heading of "lessons for climate change policy from recent events", which suggests that more acceptable schemes may prove to be directed more specifically towards individual industries, either in the form of taxes or other penalties, or in the form of incentives to improve energy efficiencies. Partial cap-and-trade schemes, for instance directed towards the power generating industry, have also been proposed. Naturally, enormous resistance against any scheme is likely to eventuate, but probably not as vehement as the resistance that demolished the universal cap-and-trade proposal in 2009. From then on, A1 may develop along lines like the following:

1. Following the inconclusive and non-binding results in Copenhagen, subsequent COP-meetings in 2010 and 2011 fail to produce firm results, whether along the lines of cap-and-trade or other possible solutions.
2. The US mid-term elections in November 2010 do not favor climate change reform.
3. The US economy recovers in 2011 with most of the business sector intact including the big energy corporations and an unreformed financial sector in which the leading survivors have gained, not lost, ability to control the market and influence public opinion and economic policy.
4. Despite the drama of the most publicized environmentally related event in 2010, the Deepwater Horizon oil spill off the coast of Louisiana recognized as the worst such incident ever, the political response is largely to shrug it off, and successfully sideline the national commission set up to investigate the matter. "Business-as-usual" prevails over environmental concern.
5. The reluctance of the western world to undertake serious reform results in China and India, in particular, abandoning some of their initial attempts to cooperate globally. Promising initiatives such as US-Chinese cooperation on solar technology drag on but without firm commitment from participating countries. The focus swings back to coal. On food security, which is a growing concern, the emphasis is also on "big technology".

Genetic engineering plays a large role in developing drought- and heat-resistant crops, which may be seen as beneficial for global food supplies but is dominated by big corporations to the virtual exclusion of other stakeholder groups.

6. The US economy is generally highly progressive, and as the decade moves on and the economy resumes full speed ahead, the impact of a strengthening education policy starts to benefit the energy sector, with a bias towards big-ticket items like fossil-fueled power plants rather than renewables. Other first-world nations also resume their growth; China, India, Brazil and others benefit from the technologically interconnected global pattern and continue their strong economic growth. Carbon capture and storage receives strong political support promoted by the coal lobbies, but the technology, as expected, proves difficult to develop economically.
7. During the late 2010s, scenario planners become aware of a 'fork in the road ahead', which can lead to two different fossil-energy paths. No one can say which fork will be taken in a future that remains essentially unknown and unpredictable. But according to these scenario planners, one path could, in the fullness of time, prove fatal for our global civilization, as we have come to know it, while the other might prove more viable though still full of major uncertainties and great risks.
8. "Fork one" encompasses the exploitation of all possible fossil fuel resources, including marginal resources such as shale oil, deep sea and polar sources, plus natural gas and the still abundant coal reserves. Scenario planners keep the name of this path as A1FI, originally given to the fossil-fuel intensive scenario devised for the IPCC Third Assessment Report in 2001. It seeks to perpetuate the fossil-fuel world of the past century, and the globalization that snowballed in the 1990s and early 2000s.
9. In "fork two", it is realized that conventional petroleum resources are peaking and likely to run out within a few decades, and that the environment needs to be brought back from the backburner (where it has sat since the end of the Copenhagen conference and subsequent COP-meetings with much talk and few commitments). The plan is to use the formidable technological capacity that is emerging internationally to develop a range of economically viable energy sources, both through renewables and through carbon sequestration designed to make fossil fuel use environmentally safe. Renewables win in the shorter term on technical and economic feasibility. Nuclear fission – an existing technology favored by many countries – also play an important role despite its long lead time (fusion remains a distant dream at least until the last quarter of the 21st century). This scenario retains the name A1B, balancing fossil with renewable and nuclear technologies. Some planners see fossil fuels being phased out over the century (the A1T variant), but that is a lengthy process.
10. Enter the scenario IPCC described from, say, 2025. The main scenario story is A1B, but the variants have been specifically analyzed to estimate limits to economic growth as the globe warms (Hoegh-Guldberg 2010b).

7.2.5 Global path to 2100 and beyond

Table 7.3, for each of the three scenario variants of A1, shows three different estimates of world GDP in the 21st century, based on the projections of the IPCC reports but then asking whether the world can continue to grow strongly under conditions of strong global warming, as the IPCC projections assume.

Table 7.3: Unadjusted and adjusted World Product: A1

	$ trillion at 1990 values			Proportion of unadjusted		Projection
	Unadjusted	"Most likely"	"Worst case"	"Most likely"	"Worst case"	$ trillion (1990)
Marker scenario A1B						
1990	20.9	20.9	20.9	100%	100%	20.9
2010	37.9	37.9	37.9	100%	100%	37.9
2035	108.1	108.1	107.8	100%	100%	108.0
2050	181.3	181.3	172.3	100%	95%	176.8
2075	341.1	321.3	256.6	94%	75%	289.0
2100	528.5	446.6	201.9	85%	38%	324.3
Scenario A1FI						
1990	20.7	20.7	20.7	100%	100%	20.7
2010	38.1	38.1	38.1	100%	100%	38.1
2035	98.6	98.6	94.9	100%	96%	96.8
2050	164.0	159.5	138.6	97%	85%	149.1
2075	329.5	268.5	103.7	81%	31%	186.1
2100	525.0	262.5	40.9	50%	8%	151.7
Scenario A1T						
1990	20.9	20.9	20.9	100%	100%	20.9
2010	36.8	36.8	36.8	100%	100%	36.8
2035	113.4	113.4	113.4	100%	100%	113.4
2050	187.1	187.1	183.6	100%	98%	185.4
2075	358.1	348.8	301.6	97%	84%	325.2
2100	555.0	497.5	309.9	90%	56%	403.7

Source: See Hoegh-Guldberg (2010b)

The base year is 2010, from which we have a "near-term" 25-year outlook for 2035, and two intermediate years (2050 and 2075) on the way to the "long-term" outlook for 2100. The first column is the unadjusted projection from the SRES report (Nakicenovic and Swart 2000), showing continued growth for all three scenario variants from a level of about $38 trillion in 2010 to $530-550 trillion in 2100 (the variation is due to the Third Assessment teams in 2001 choosing slightly different versions of the A1 scenario family as the official scenarios). The values are in 1990 dollars. The actual global GDP in 2008 was $60.6 trillion according to the World Bank, up from $21.8 trillion in 1990 (slightly above the base year figures in Table 7.3). The projections could be converted to 2010 values using a factor of 1.6, but it is the trends rather than the levels that are of most interest.

The next two columns of Table 7.3 show adjustments based on the assumptions made on the basis of global warming trends taken from IPCC's Fourth Assessment Report (see Hoegh-Guldberg 2010b). With most data being available on average temperatures, these become the proxy for other symptoms of climate change including rising sea levels, more violent storms, and ocean acidification. Further work and more sophisticated modeling would be needed to check the relationships between temperatures and the other variables.

The assumptions (Hoegh-Guldberg 2010b, Figure 3) are that GDP starts to get affected when global average temperatures reach 1.5^{O}C above pre-industrial levels, which is about twice the increase already recorded, with more increases already in the pipeline due to delays in the carbon cycle and other factors. It was noted in Section 2.2 that GDP is assumed to be reduced by 5% at +2^{O}C, 50% at +4^{O}C, and 90% at +6^{O}C. Hoegh-Guldberg (2010b) contains sensitivity analysis which largely supports the base case shown here.

The "most likely" middle-of-the-road A1 scenario (A1B), adjusted for expected global temperature increases, shows continued growth to a level 15% below the unadjusted IPCC scenario, but in the worst case deviations from the unadjusted projection start before 2050 and there is a drop of over 20% in the global GDP in the last quarter of the century, to a level of only 38% of the unadjusted projection. The yellow right-hand column of Table 7.3 (midway between the "most likely" and "worst" cases as explained in Section 6.6) suggests continuous growth through the century but at rapidly declining rates, from 4.3% per annum between 2010 and 2035 to 3.3% pa from 2035 to 2050 and 2.0% pa 2050-75, to only 0.5% pa in the final quarter-century to 2100.

The most likely path for the fossil-intensive variant, A1FI, starts to fall below the unadjusted projection before 2050 and declines from about 2075 to a level exactly half of the unadjusted projection for 2100. In the worst case, A1FI falls short of the unadjusted path from before 2035, reaches its peak around 2050 when it is already 15% below the unadjusted projection, and drops to only 8% of that projection in 2100, when the assumed global temperature increase is 6.4% above pre-industrial levels. The worst case in more recent projections has a higher temperature change, but this illustration must suffice here.

If the global economic growth scenario includes replacing fossil fuels with renewables, the most likely case is strong and continued growth to almost $500 trillion by 2100, 90% of the base projection. However, the worst case sees virtual cessation of economic growth from 2075 based on the IPCC's own assessment of global warming – in fact, the more detailed projections (Hoegh-Guldberg 2010b) show actual decline in the last decade of the century.

In the absence of mitigating action, the prospects from the second half of the 21st century look risky indeed. Looking beyond 2100, this does not augur well for what might happen in the next century, with the trend accelerating towards higher temperatures, and there is always a risk that the scenario will tilt further towards the worst case during this century, causing the world GDP to decline from, say, 2075. If left to run their course, the A1 scenarios all lead to utterly unpredictable, chaotic situations in the 22nd century – probably collapse under A1FI and the best chance for our civilizations to survive under A1T.

Some projections may suggest that there will be time to adjust even going down a high-growth fossil fuel path – after all, even in the worst case growth continues into the middle of the century. This is unfortunately not so. At the lower growth projections, CO_2 emissions would be reduced compared with the unadjusted IPCC trajectories, but the lower growth has itself been caused by higher temperatures, so the damage has already been done.

This section has shown is that the IPCC rates of global economic growth won't happen if our assumptions about the world's inability to keep up the assumed economic growth in conditions of rapid warming are correct. It may be argued, of course, that with strong economic growth, a much richer world population would be able to shield itself – all nine billion of us by 2050 – in suitable housing and other environments. This stretches the credibility; at least it suggests that a mammoth part of the world's additional resources would be needed as protection against excessive temperatures, and the benefits will differ enormously between rich and poor countries, disadvantaging the latter.

In conclusion, even the best case A1 scenario is likely to lead to temperature increases above +2^{O}C; in the worst case, even A1T despite its switch to renewable energy sources shows temperature changes approaching +4^{O}C by 2100. Worst cases, as stressed elsewhere in this report, have had an unfortunate tendency to move from the "unlikely" end of the probability distribution towards its center (Garnaut 2008), or in Weitzman's estimation (2009) a larger proportion of "unlikely" events have become more likely – the tails of the distribution have become "fatter".

7.2.6 THE UNITED STATES IN AN A1 CONTEXT

In many ways, the global scenario is reflected, and to a considerable extent led, by the United States, though the extent would vary with the scenario. Rather than spelling out the obvious consequences in terms of energy policy, we have chosen to present the additional perspective based on Murphy (2007). The addendum to Hoegh-Guldberg (2010a) outlines three scenario stories of his based on "fast-forwarding" some worrying current trends.

The first scenario concentrates strongly on homeland defense, the second on disintegration of national power as large cities all over the world develop into powerful city-states with their own agendas and a great potential for conflict, and the third on the uninterrupted rise of private corporate power, with fifty corporations already among the 100 largest "economies" in the world. All three are "A-type" economy-dominated scenarios, and the last is most readily compatible with A1. The first two scenarios might develop as part of the regionalized economic scenario A2, complete with rising conflict as described in Section 7.4. However, America's interest in policing regions of strategic economic importance is also relevant in the A1 scenarios to protect its global hegemony.

Murphy's antidote against these unfavorable scenarios is his "hundred-year workout plan" (Section 7.1.4). It is unlikely to be followed at least in the balanced-energy and fossil-intensive variants of A1 because these futures tend to follow past trends. It was suggested in the previous paragraph that the role of the United States as self-appointed global policeman would cause it to continue a strong military presence to maintain influence and control over strategically important areas, such as oil-producing regions. A1 could also see continued rise in corporate power on a truly global scale, undisputed lords of the world's water, food, information, health, energy, transportation, software, music, security, and violence, as listed by Murphy (2007, p 200).

Whether or not the world continues to be dominated by America, such a perspective would become truly frightening when or if the world economy starts to run into growth bottlenecks (Hoegh-Guldberg 2010b). Macroeconomic policy would also fly in the face of the reforms suggested by the economics of climate change and how to deal with unbridled speculative activities (Hoegh-Guldberg 2010c).

As far as the limits to growth due to climate change and global warming are concerned, the United States with its great wealth may be able to protect most of its citizens, though maybe not its least privileged groups, in conditions of growing discomfort, but much of the developing world couldn't, and if and when global GDP begins to fall in the worst-case fossil-intensive scenario, the US economy will suffer badly too. Furthermore, unfavorable natural conditions will include increasing droughts, dust bowls, forest fires, damage from increased hurricane and other violent weather activity, and sea-level rise (where the whole of southern Florida and large parts of the coastal parts of the State are particularly vulnerable).

7.2.7 Zooming in on the Florida Keys

Table 7.4: Global and local projections for Scenario A1

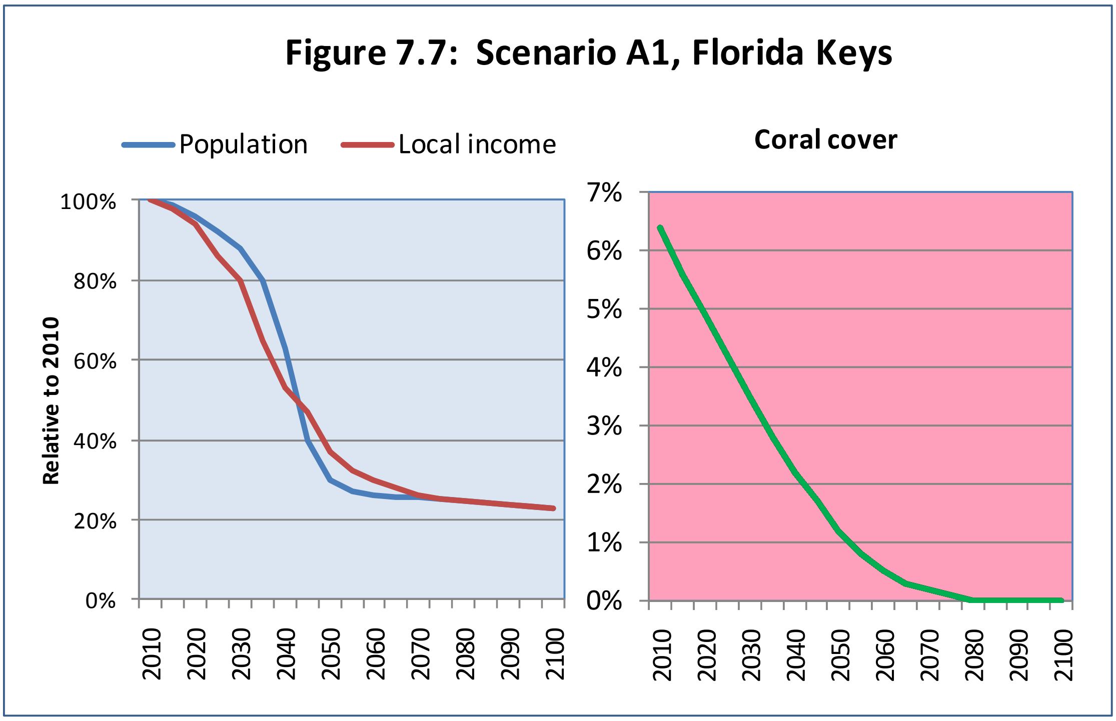
Scenario A1	2010	2035	2050	2075	2100
Global temperature increase (^{o}C)	0.8	2.0	3.0	3.5	4.0
Global sea-level rise (cm)	-	12	37	57	80
Global ocean acidification (pH)	8.1	8.0	7.9	7.8	7.7
Annual world GDP change	3.0%	4.3%	3.3%	2.0%	0.5%
Keys population	72,000	57,600	21,600	18,000	16,600
Population relative to 2010	100%	80%	30%	25%	23%
Keys coral cover	6.4%	2.8%	1.2%	0.1%	0.0%
Coral cover relative to 2010	100%	44%	19%	2%	0%
Keys area remaining	100%	80%	30%	25%	23%
Value of Keys area remaining	100%	86%	56%	49%	45%
Keys income relative to 2010	100%	65%	37%	25%	23%

The high global economic growth suggested by Table 7.4 might initially have been thought to benefit the Florida Keys in terms of income, but this would be rapidly dissipated by the physical reality of sea-level rise. The population is assumed to fall in proportion to the loss of land, with carrying capacity stretched to the limits, and the remaining wealth will probably be increasingly absorbed elsewhere.

The most striking result of Chris Bergh's research (2009), analyzed in Section 7.1.5, is the dramatic land loss between 2035 and 2050 in the A1 scenario as the global temperature increases from 2^{O}C to 3^{O}C above pre-industrial levels, and the global sea level rises from 12 to 37 cm above the base level. This is estimated to cause the remaining land area in the Keys to decline from 80% to 30% of currently existing levels. Bergh (2009) is on record for projecting 38% land loss at the *most optimistic* 18 cm IPCC sea-level rise. At the *most likely* IPCC estimate of 28 cm global sea-level rise, Table 7.1 suggested that 55% of the Keys would be inundated.

The Keys population is assumed to be directly correlated with the remaining land area, which means a reduction from 72,000 persons in 2010 to 57,600 in 2035 and 21,600 in 2050, after which the decline becomes less dramatic (Table 7.4). This development could not have been estimated without Chris Bergh's research into the connection between the topography of the Keys and the projected sea level. Intuitively, the population decline would have been expected to be much more gradual than Figure 7.7 shows.

The model proposed for the connection between remaining land values and local incomes in the Keys has two components: the proportion of total value remaining according to Bergh



(2009), and coral cover, used as the only proxy of future marine-based tourism potential we know. Giving these two indicators equal weight results in a timeline not dissimilar from the population trend: strong decline, especially between 2035 and 2050, and then less of a decline. Both indicators end up in 2100 just above 20% of the 2010 level. The loss of coral cover indicates the loss of marine-based tourism as it is known today, and the value of the remaining assets will increasingly benefit external rather than local interests.

The economic analysis of the visitor survey conducted under NOAA auspices for 2007-08 (Section 6.3) showed total spending by cruise-ship passengers increasing strongly despite a fall in per capita spending based in Key West (Tables 6.22 and 6.25), and spending by overnight visitors also increased compared with 1995-96 (Table 6.25). These factors were important although the total increase between the two survey dates (Table 6.26) was largely due to more people owning or leasing condominiums and time-share accommodation, but having their residence elsewhere. The continued role of cruise ships and expatriate people renting or owning premises in the Keys would help explain how an increasing share of the total value of Keys assets would be owned outside the Keys.

The coral cover is estimated to be down to 1.2% by 2050 and to disappear by 2075, from the 6.4% estimated for 2010. Temperatures will increase to very unpleasant levels at least from 2050, requiring progressively better (and dearer) building insulation. The oceans will become progressively more acid. A decline in pH to 7.7 would have disastrous consequences not only for coral reefs but for a broad range of other calcareous organisms in the Southern Ocean in particular. There is also evidence that an acidified ocean affects the ability of fish to navigate (Hoegh-Guldberg (2010a), referring to Raven et al. 2005, and Munday et al. 2009). In the Keys, it all points to continuing decline of marine-based tourism.

The population of the Florida Keys, already declining with an increasing number of well-to-do absentee owners of condominiums and similar types of accommodation, will fall to a low projected level of 16,600, compatible with the inundation (Figure 7.4). We don't know whether they will be rich, and maybe even fewer in number. The economic mainstay, tourism, will be progressively affected, though the number of cruise-ship passengers may revive in a richer world in the next 25 years, benefiting Key West (to the extent that the sea-level rise is controlled there) and continuing the trend towards a higher share of land-based activities found in the NOAA visitor surveys. Sailing and boating may continue but based on other facilities as there will be little infrastructure in the Keys after 2050 to support these activities.

In summary, even the "balanced" fossil fuel/renewable growth scenario will leave the Keys devastated. Furthermore, there is no light at the end of the tunnel in the 22nd century if the global Scenario A1B is allowed to run its course. By then, not just the Keys but the whole A1 world is projected to go into reverse.

7.3 B1: GLOBAL ENVIRONMENTAL FOCUS

7.3.1 THE IPCC STORYLINE

The central elements of the B1 future are a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development. Heightened environmental consciousness might be brought about by clear evidence that impacts of natural resource use, such as deforestation, soil depletion, over-fishing, and global and regional pollution, pose a serious threat to the continuation of human life on Earth. In the B1 storyline, governments, businesses, the media, and the public pay increased attention to the environmental and social aspects of development. Technological change plays an important role. At the same time, however, the storyline does not include any climate policies, to reflect the SRES terms of reference. Nevertheless, such a possible future cannot be ruled out.

A "Conventional Worlds – Policy Reform" scenario from 1997 is a good example of such a future, although it includes climate policies. Another scenario from 1995 describes a reaction to early decades of crime and chaos, in which community values triumph over individualist ones and lead to resource-friendly lifestyles based on clean and light technologies. This scenario includes a voluntary embrace of cohesion, cooperation, and reduced consumption, backed by legislation and even corporate policies. In a normative scenario from 1997, the world achieves an environmentally sustainable economy by 2050, primarily through education to develop human potential. In a scenario from 1992, economic equilibrium and innovation lead to sustainable development. The "ecologically driven" scenarios by WEC (1993) and IIASA-WEC (1998) with accelerated efficiency improvements in resource use share several of the characteristics of the B1 type of future, as does an egalitarian utopia scenario from 1997.

Many additional scenarios in the literature could be seen as examples of this family, but may describe the changes as more fundamental than those of B1. One scenario stresses the role of global technological innovation in addition to enlightened corporate actions, government policies, and empowerment of local groups. In another, from the Millennium Institute, resources are shared more equitably to the benefit of all and the greater safety of humanity. Other scenarios from 1989 and 1998 examine sustainable futures.

Economic development in B1 is balanced, and efforts to achieve equitable income distribution are effective. As in A1, the B1 storyline describes a fast-changing and convergent world, but the priorities differ. Whereas the A1 world invests its gains from increased productivity and know-how primarily in further economic growth, the B1 world invests a large part of its gains in improved efficiency of resource use ("dematerialization"), equity, social institutions, and environmental protection.

A strong welfare net prevents social exclusion on the basis of poverty. However, counter-currents may develop and in some places people may not conform to the main social and environmental intentions of the mainstream in this scenario family. Massive income redistribution and presumably high taxation levels may adversely affect the economic efficiency and functioning of world markets.

Particular effort is devoted to increases in resource efficiency to achieve the goals stated above. Incentive systems, combined with advances in international institutions, permit the rapid diffusion of cleaner technology. To this end, R&D is also enhanced, together with education and the capacity building for clean and equitable development. Organizational measures are adopted to reduce material wastage by maximizing reuse and recycling. The combination of technical and organizational change yields high levels of material and energy saving, as well as reductions in pollution. Labor productivity also improves as a by-product of these efforts. Alternative scenarios considered within the B1 family include different rates of GDP growth and dematerialization (e.g., decline in energy and material intensities).

The demographic transition to low mortality and fertility occurs at the same rate as in A1, but for different reasons as it is motivated partly by social and environmental concerns. Global population reaches nine billion by 2050 and declines to about seven billion by 2100. This is a world with high levels of economic activity (a global GDP of around US$350 trillion by 2100) and significant and deliberate progress toward international and national income equality. Global income per capita in 2050 averages US$13,000, one-third lower than in A1. A higher proportion of this income is spent on services rather than on material goods, and on quality rather than quantity, because the emphasis on material goods is less and also resource prices are increased by environmental taxation.

The B1 storyline sees a relatively smooth transition to alternative energy systems as conventional oil and gas resources decline. There is extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition, but the major push is toward post-fossil technologies, driven in large part by environmental concerns.

Given the high environmental consciousness and institutional effectiveness in the B1 storyline, environmental quality is high, as most potentially negative environmental aspects of rapid development are anticipated and effectively dealt with locally, nationally, and internationally. For example, trans-boundary air pollution (acid rain) is basically eliminated in the long term. Land use is managed carefully to counteract the impacts of activities potentially damaging to the environment. Cities are compact and designed for public and non-motorized transport, with suburban developments tightly controlled. Strong incentives for low-input, low-impact agriculture, along with maintenance of large areas of wilderness, contribute to high food prices with much lower levels of meat consumption than those in A1. These proactive local and regional environmental measures and policies also lead to relatively low greenhouse gas emissions, even in the absence of explicit interventions to mitigate climate change.

7.3.2 Would this scenario story have been written differently in 2010?

The philosophy has not changed since the B1 scenario story was written. The first two sentences in IPCC's description set the stage – note the "and social" which is often overlooked but is a natural ally of environmental consciousness (so is "cultural"). That community values prevail over individualist ones is natural, given the general philosophy behind the B1 scenario. The use of the word "utopian" describing a scenario written in 1997 marks a step towards the way environmentally friendly policies are now perceived. Today, with an even bigger need to combat climate change, this scenario provides the best path towards avoiding its worst effects, and while it may be resisted there is no longer anything utopian about such a policy.

The main caveat is that the projected greenhouse gas levels are much higher than is becoming acceptable if the world average temperature is to stay within +2^{O}C of pre-industrial levels. Interestingly, the emphasis on technological change in the terms used in Hoegh-Guldberg (2010d) is on energy efficiency first and land use second. The transition to renewable technologies is seen as essential but told in two sentences, without specification.

The main new features that should be added to the story told today concerns the greater urgency to bring down greenhouse gas emissions with all possible acceptable technologies: a rapid switch to renewables, a probable role for nuclear technologies, increased emphasis on energy efficiencies, a higher profile for agricultural land use and forest management, and the use and protection of oceanic sinks. It is encouraging that genuine innovative activities are beginning to spread across a larger number of nations (Hoegh-Guldberg 2010d), but it is also essential to keep diffusing the appropriate technologies to all countries including the poorest and least developed ones.

7.3.3 Current physical, economic and technological influences

An environmentally sensitive scenario with a global perspective is most likely to lead to a minimization of average global temperatures to 2^{O}C, while achieving a reduction to <350 ppm atmospheric CO_2. The B1 scenario according to the Fourth Assessment Report has a "most likely" average temperature increase of 1.8^{O}C, and a worst-case rise of 2.9^{O}C, which is well into the risky range according to recent assessments. The projected level of atmospheric CO_2 in 2100 is 545 ppm, which is too high for current comfort but the lowest of the Fourth Assessment Report scenarios (Hoegh-Guldberg 2010a).

B1 is the only scenario showing continuing growth in the worst case when constraints are put into the model to reflect reactions of economic growth to warming. All other worst-case scenarios show a change to economic decline sometime in the second half of the 21st century (Hoegh-Guldberg 2010b, Figure 5).

Economic policy may be assumed to change from the past lack of sensitivity to the economics of climate change, and to curb the excesses of financial sector speculation that caused the current economic downturn. It is also plausible that there will be a stronger tendency for economics to cross-fertilize with other social and physical sciences to the benefit of all, as discussed under the general heading of complexity theory (Hoegh-Guldberg

2010c). Climate policies are likely to favor incentives, whether to promote renewable technologies or energy efficiency. Carbon taxes rather than emissions trading schemes, and specific industry policies, may become the norm. There will be a strong thrust toward assisting less developed countries to adopt renewable energy technologies and efficient use of energy, aimed at small communities as well as major technological projects.

Technology will be balanced, with the development of renewable energies on a wide range of scales (some will be economically feasible at mega-level, but many in smaller units). The technologies include wind, solar, geothermal and others, already at an advanced stage of development and capable of either filling "wedges" in the Pacala/Socolow (2004) sense of contributing to the global need for alternative energy sources, or to fit local community needs (the sum total of which might itself fill "wedges"). Technological progress will also be strongly geared towards energy efficiencies and towards developing and protecting forestry, agricultural and "blue carbon" sinks – the latter directed towards the worldwide protection of mangroves, seagrasses, salt marshes, coastal wetlands and estuaries which are essential for capturing CO_2 for long-term storage in the oceans (Nellemann et al. 2009).

An important part of the technological thrust, while differentiated in scale, will be towards assisting less developed countries at local level. This includes assistance to improve food security through better infrastructure, including roads and storage facilities, backed by thoughtfully administered advice and training to improve local management skills. Genetically engineered crops and other products will be promoted after extensive ecological safety tests, based on strong advances in biotechnology (Hoegh-Guldberg 2010d). Other agricultural technologies aimed at attaining better biodiversity as well as food security will maintain a strong position, along the lines of Shiva (2005) and others.

7.3.4 Linking the present to the storyline

Despite the disappointment of the conference failing to reach binding agreement, the "Copenhagen Accord" presented on the last day of the COP-15 meeting in December 2009 had sufficient positive content to preserve a spirit of cooperation and sense of urgency for the two subsequent annual meetings to achieve commitment from both the developed and the developing worlds. The Bali Action Plan or Bali "Road Map" of 2007 had already established a shared long-term vision and four "building blocks" of increased mitigation of greenhouse gases, adaptation to climate change, technology transfer and development, and financing (the latter especially important in securing assistance to less developed countries).

Efforts to include prevention of deforestation in the Clean Development Mechanism were also met with approval in principle. This was important not only for the direct recognition, but also because of the links with agriculturally based technologies in the effort to improve the planet's carbon sinks – too long underestimated in the fight to control greenhouse gases.

While the Copenhagen meeting failed to quantify the essential elements of a fair and effective deal on climate change, the continued negotiations binding the annual COP meetings together were intensified, and a binding agreement was signed by all parties at the 2011 meeting. Ratification by a sufficient number of member nations followed in time to provide a effective successor to the Kyoto Agreement.

In May 2010, following only a month after President Obama's decision to allow exploration for oil along the Atlantic coast, in the Mexican Gulf, and north of Alaska, the Deepwater Horizon well, an unconventional petroleum source in the Gulf, caused the worst oil spill disaster in American history. The President took strong action as it became clear that the event was indeed catastrophic, and assumed full leadership. He declared on June 3 (*Washington Post* video):

"What kind of energy future can ensure our long-term prospects? The catastrophe unfolding in the Gulf right now may prove to be a result of human error or a corporation taking advantage of shortcuts to compromise safety, or a combination of both. I have launched a national commission so that the American people will have answers on exactly what happened. We have to acknowledge the inherent risks of drilling four miles beneath the surface of the earth; these risks are bound to increase the harder oil extraction becomes. Once this is acknowledged, that America runs fully on fossil fuels should not be the vision we have for our children and grandchildren."

The US Administration meanwhile abandoned its efforts to put through a universal cap-and-trade bill in favor of a version of what was originally known as the Kerry-Lieberman-Graham proposal which these senators had been asked to put in train urgently during the first quarter of 2010. The mid-term elections intervened, however, and the first climate bill was passed in 2011, switching the emphasis from the overall penalty approach of cap-and-trade to incentives aimed at individual industries, coupled with control of polluters. A partial cap-and-trade scheme was imposed on the power generation industry, though considerable concessions were needed to reduce the sense of injustice that the industry claimed to feel.

The 2011 climate bill succeeded in making the unconventional fossil fuel sources brought into play in the A1 scenario unrealistic competitors, despite the prospect of conventional oil resources running out. Coal suffered because the cost of mandatory CCS technology for new plants was not coming down as fast as hoped, a problem that proved even more serious when retrofitting existing plants. All these factors caused the dynamics of the energy sector to change more rapidly towards renewables in the second half of the 2010s.

The Deepwater Horizon spill, with its damage to the most important wetlands in the nation, on the coast of Louisiana, and threatening the ecosystems of the Florida Keys and into the wider Caribbean (though this was largely averted), helped returning public opinion towards environmental concerns. Meanwhile, evidence of climate change became more apparent, with record temperatures, more frequent hurricanes and extreme monsoonal events, and more evidence of sea-level rise. The widespread effect of ocean acidification on calcareous marine organisms everywhere raised the public consciousness of this factor to new levels. All this helped an economically viable B1 scenario come into play naturally from the mid 2020s.

7.3.5 Global path to 2100 and beyond

The unadjusted path from the IPCC's Third Assessment Report shows growth to almost nine times the current world GDP (Table 7.5). Assuming these rates are indeed achievable, they will be practically reached in the most likely case of global warming rates, and even in the worst B1 case world GDP may still grow to over 80% of the unadjusted case at the end of the century.

This is clearly the best result of any of the scenarios, but although the assumed level of atmospheric CO_2 is the lowest according to Table 1 (in Hoegh-Guldberg 2010b), it is still about 200 ppm higher than what appears to be the emerging "safe" standard of 350 ppm or less.

Table 7.5: Unadjusted and adjusted World Product: B1

	$ trillion at 1990 values			Proportion of unadjusted		Projection
	Unadjusted	"Most likely"	"Worst case"	"Most likely"	"Worst case"	$ trillion (1990)
1990	21.0	21.0	21.0	100%	100%	21.0
2010	37.3	37.3	37.3	100%	100%	37.3
2035	86.9	86.9	86.9	100%	100%	86.9
2050	135.6	135.6	135.6	100%	100%	135.6
2075	229.1	229.1	214.6	100%	94%	221.9
2100	328.4	319.3	270.4	97%	82%	294.9

Source: See Hoegh-Guldberg (2010b)

It was concluded in the discussion of whether the B1 scenario would have been written differently today that for B1 to be adopted as the new model, a concerted effort will be required to marshal the world's resources and cooperation to bring in a widening range of renewable technologies to suit all economic and physical environments, coupled with renewed efforts to maximize energy efficiencies, and to encourage better and more universally applied management of rural and forest resources, and oceanic carbon sinks. In other words, the general B1 philosophy remains, but more is needed.

Such a "super-B1" scenario offers the best hope for the world, and the Florida Keys, over the century and beyond, to help reduce atmospheric CO_2 to 350 ppm or below. The global economic growth rate in Table 7.5 might even be achievable across the century, especially if these efforts are augmented with a successful boost to technological innovation and diffusion.

The advent of the Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) is promising in this respect. Its request for information or RFI, dated August 2009, sets a new provocative tone, requiring "*disruptive new, extremely low-cost approaches to manufacturing high quality products*" aimed at "*translating cutting-edge scientific discoveries into transformational new energy technologies*". (Hoegh-Guldberg 2010d)

7.3.6 THE UNITED STATES IN A B1 CONTEXT

The four items of Murphy's (2007) "hundred-year workout plan" fit in well with the B1 philosophy. Instilling an appreciation of the wider world by being open to immigrants and other outside influences that can help enrich both culture and technology, and supporting governments for their positive contributions, promoting assimilation, and lightening the national military burden are all part of a more open and positive outlook that goes well with a commitment to environmentally friendly policies.

7.3.7 ZOOMING IN ON THE FLORIDA KEYS

This is clearly the best-case scenario despite the need to strengthen it globally to meet more stringent atmospheric CO_2 targets. It is supported in the Keys by the prevailing community spirit, with sufficient people being attracted to the lifestyle (including the opportunity to base this on renewable energy sources as is already happening on No Name Key). Young people also respond by more of them staying rather than abandoning the Keys; an issue that came up at the Key Largo scenario-planning workshop in 2008 at the initiative of two young women professionals (Appendix 2, under the heading of "Key Largo: carrying capacity"). Another young woman participant in the same workshop called the Keys potentially "a living laboratory for climate change", which could help attract young people.

Due to good management and local community support, the resilience work is as successful as can possibly be expected, and despite the ocean warming helps allowing much of the coral cover to remain. Sea-level rise will happen but to a relatively limited extent, and work to mitigate and adapt as outlined by Bergh (2009) will prove successful, offsetting some of the impact of physical land loss. Efficient sanctuary management and land-based conservation work is crucial in this scenario.

Table 7.6: Global and local projections for Scenario B1

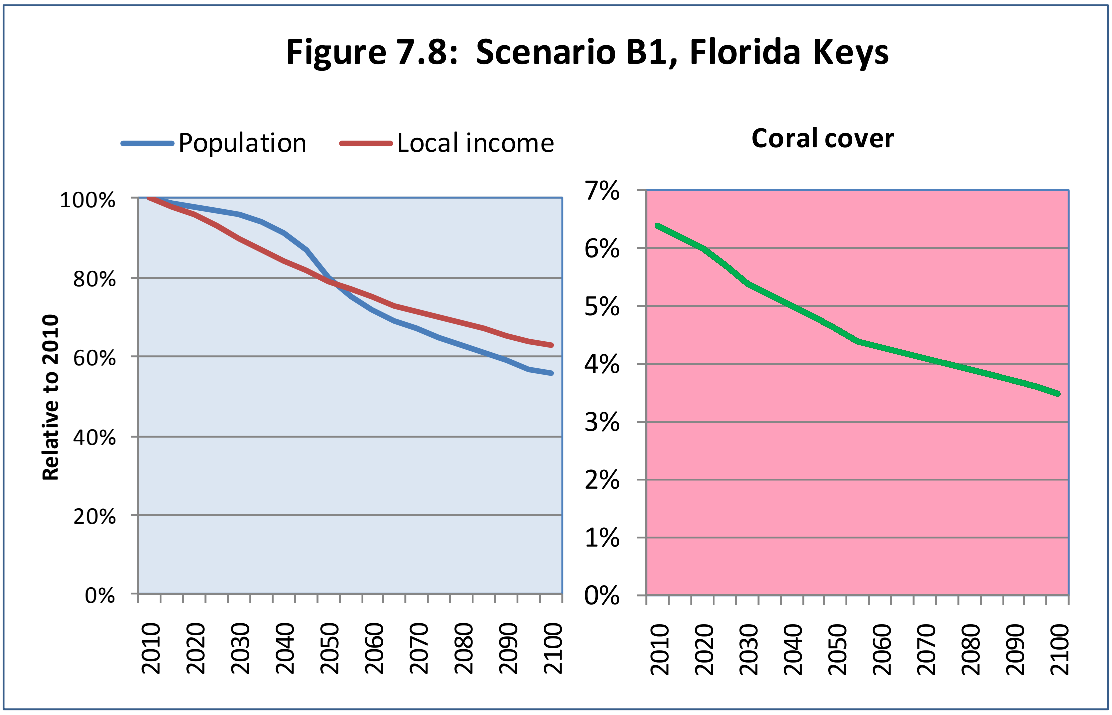
Scenario B1	2010	2035	2050	2075	2100
Global temperature increase (^{o}C)	0.8	1.5	2.0	2.3	2.5
Global sea-level rise (cm)	-	6	12	17	22
Global ocean acidification (pH)	8.10	8.08	8.06	8.03	8.00
Annual world GDP change	3.0%	3.4%	3.0%	2.0%	1.1%
Keys population	72,000	67,700	57,600	46,800	40,300
Population relative to 2010	100%	94%	80%	65%	56%
Keys coral cover	6.4%	5.2%	4.6%	4.0%	3.5%
Coral cover relative to 2010	100%	81%	72%	63%	55%
Keys area remaining	100%	94%	80%	65%	56%
Value of Keys area remaining	100%	95%	86%	77%	71%
Keys income relative to 2010	100%	88%	79%	70%	63%

The projections in Table 7.6 attempt to reflect the best-case IPCC scenario for the Florida Keys. The average global temperature is assumed to rise by 2.5^{O}C above pre-industrial levels by the end of the century. The sea-level rise compatible with this scenario is 22 cm, at which level 44% of the Keys would be inundated. This is reflected in the population declining from 72,000 currently to 40,300 in 2100.

Ocean acidification is an external variable, projected to decline from 8.1 to 8.0 (Table 7.6). This is strictly an assumption, and it should be borne in mind that one pH point represents a 30% increase in acidity. Ocean chemistry remains a threat even in the most benign scenario.

The relatively high projected coral cover (3.5% in 2100) is assumed to be consistent with the assumption on acidification, as well as being crucially dependent on the continued resilience policy of the FKNMS and other organizations, and the community's active involvement. Finally, the income estimates in Table 7.6 are made on the assumption that there will be a viable tourist industry with the coral cover in place through the century, backed up by land-based activities associated mainly with Key West. The realism of this is also an assumption, but the City of Key West is beginning to factor sea-level rise into its engineering and construction decisions (Bergh 2009, p 28). It is important, in any case, that Key West remains a crucial part of tourism, and there is cooperation between the historical and nature-based part of the industry.

The graphic results in Figure 7.8 for the main local variables contrast dramatically with the results shown in Figure 7.7 for the growth-orientated A1B scenario.



7.4 A2: Regional economic focus

7.4.1 The IPCC storyline

The A2 scenario family represents a differentiated world. Compared to the A1 storyline it is characterized by lower trade flows, relatively slow capital stock turnover, and slower technological change. The A2 world "consolidates" into a series of economic regions. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions are characteristic for this future. Economic growth is uneven and the income gap between now-industrialized and developing parts of the world does not narrow, unlike in the A1 and B1 scenario families.

The A2 world has less international cooperation than the A1 or B1 worlds. People, ideas, and capital are less mobile so that technology diffuses more slowly than in the other scenario families. International disparities in productivity, and hence income per capita, are largely maintained or increased in absolute terms. With the emphasis on family and community life, fertility rates decline relatively slowly, which makes the A2 population the largest among the storylines (15 billion by 2100). Global average per capita income in A2 is low relative to other storylines (especially A1 and B1), reaching about US$7,200 per capita by 2050 and US$16,000 in 2100. By 2100 the global GDP reaches about US$250 trillion.

Technological change in the A2 scenario world is also more heterogeneous than that in A1. It is more rapid than average in some regions and slower in others, as industry adjusts to local resource endowments, culture, and education levels. Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor in resources place a very high priority on minimizing import dependence through technological innovation to improve resource efficiency and make use of substitute inputs. The fuel mix in different regions is determined primarily by resource availability. High-income but resource-poor regions shift toward advanced post-fossil technologies (renewables or nuclear), while low-income resource-rich regions generally rely on older fossil technologies. Final energy intensities in A2 decline with a pace of 0.5 to 0.7% per year.

In the A2 world, social and political structures diversify; some regions move toward stronger welfare systems and reduced income inequality, while others move toward "leaner" government and more heterogeneous income distributions. With substantial food requirements, agricultural productivity in the A2 world is one of the main focus areas for innovation and research, development, and deployment (RD&D) efforts, and environmental concerns. Initial high levels of soil erosion and water pollution are eventually eased through the local development of more sustainable high-yield agriculture. Although attention is given to potential local and regional environmental damage, it is not uniform across regions. Global environmental concerns are relatively weak, although attempts are made to bring regional and local pollution under control and to maintain environmental amenities.

As in other SRES storylines, the intention in this storyline is not to imply that the underlying dynamics of A2 are either good or bad. The literature suggests that such a world could have many positive aspects from the current perspective, such as the increasing tendency toward cultural pluralism with mutual acceptance of diversity and fundamental differences. Various scenarios from the literature may be grouped under this scenario family. One example is a society in which most nations protect their threatened cultural identities. Some regions might achieve relative stability while others suffer under civil disorders. In one scenario, economic growth slows down because of a strengthening of protectionist trade blocks. In another, major economic blocs impose standards and regulations on smaller countries. One scenario explores the possibility of regional spheres of influence, whereas another reflects resistance to globalization and liberalization of markets. Noting the tensions that arise as societies adopt western technology without western culture, Samuel Huntington in 1996 suggested that conflicts between civilizations rather than globalizing economies may determine the geopolitical future of the world.

7.4.2 WOULD THIS SCENARIO STORY HAVE BEEN WRITTEN DIFFERENTLY IN 2010?

The idea that the world economy might divide into a number of distinct regions is not difficult to imagine; even though the current observed trend is towards globalization the trend is by no means undisputed. There are regions today that could conceivably become isolated and start following their own different social, cultural and economic paths; North America versus Central America, Sub-Saharan Africa in whole or in part, and the Middle East and North Africa may be among such candidates. Smaller but economically powerful regions may emerge as independent international competitors, like the “city-states” and corporate giants mentioned in Section 7.4.6, below.

At the other extreme, China could become a very large isolated region. The World Bank (2009) discusses the country's environmental fragility: "China's rapid growth is now a driving force in the global economy and is achieving unprecedented rates of poverty reduction. However, growth is also seriously damaging the natural resource base and generating major environmental liabilities. The country's environmental problems include land degradation, deteriorating water quality and water scarcity, severe air pollution and declining natural forest cover. These problems threaten the health and prospects of current and future generations and are undermining the sustainability of long-term growth."

China's recent economic growth has damaged the environment, but the harm goes further back not just to the foundation of the communist regime, but centuries and millennia before. As the World Bank publication points out, the problems today are manifold. While exacerbated by prosperity, the problems are also more manageable while the economy is growing. China's massive "cleantech" plans (see Hoegh-Guldberg 2010d) may stall as the world fragments into the A2 scenario, especially if the plans become derailed by environmental and economic disasters.

Whichever way the regionalization happens, the impact would differ from region to region. As the scenario story tells us, disturbingly, there is no narrowing between developing and developed countries, technological diffusion slows down, and fertility comes down slowly, resulting in a world population of 15 billion in 2100 (maybe 12 or 13 billion if written today, reflecting recent trends in total fertility rates). Together with the other impacts of climate change, aggravated by a relative lack of attention to environmental matters, A2 seems to be a recipe for growth in the number and severity of regional conflicts.

Agricultural productivity in these circumstances becomes a main focus, with basic food requirements the paramount consideration. Global environmental concerns wane, replaced by a focus on regional issues and local pollution control. Hence, climate change becomes a weaker issue, too hard to handle in the global perspective that it needs. Food security remains important, but the global mechanisms governing it are also diminished.

The positive characteristics of this scenario, supporting cultural pluralism and diversity, do not outweigh the global focus that might support cultural diversity in an environmentally and culturally benign scenario, such as B1. Planning for cultural integrity is not explicitly part of B1, but there are reasons to believe that it could be encouraged in that setting. It would actually strengthen the environmentally friendly scenario with its emphasis on preserving biodiversity to nurture vigorously creative cultural and artistic diversity in every nation; the B1 story's coupling of ecological and social sustainability suggests culture as a natural third leg. A2 is left in the worst possible position compared with alternative worlds without real opportunities even to nurture its own cultural pluralism and diversity on an ongoing basis.

In summary, scenario A2 is exposed, as well as being burdened with environmentally unsustainable population growth. Logically it represents one of the quadrants of the IPCC tree diagram in Figure 7.1, and the concept of a regionalized environmentally ineffectual worst-case scenario is eminently plausible. Some of its basic assumptions would gain from a re-examination, including an updated review of escalating conflict associated with local warfare and international terrorism. It is hard to imagine an A2 scenario written in 2010 that wouldn't rival the fossil-intensive A1 scenario as the worst case for climate change, with the added disadvantage that it would be more difficult for the poorer and more fragmented A2 world to take adaptive action to avoid the worst effects.

7.4.3 CURRENT PHYSICAL, ECONOMIC AND TECHNOLOGICAL INFLUENCES

Scenario A2 is the second-most polluting scenario in the Fourth Assessment Report (Table 1 in Hoegh-Guldberg 2010b) with a most likely temperature rise of 3.4^{O}C and a worst-case 5.4^{O}C, and reaching 846 ppm CO_2 by 2100. It shows the second-lowest economic growth of all scenarios with economic decline from 2090 in the most likely case and from 2060 in the worst case (Table 5 in Hoegh-Guldberg 2010b). The lowest economic growth in the Fourth Assessment Report, by a marginal amount only, is the regionalized environmental B2 scenario, which if rewritten today would show a more benign pattern (see Section 7.5).

Section 7.4.2 suggests that A2 would suffer from an update. The risk of armed conflict as the population multiplies, regions developing at different rates, and food sources struggling to keep up, suggests that the global economy may start going backwards even before the time suggested by Hoegh-Guldberg (2010b), summarized below. Any general direction of economic policy would be hard to detect in this regionally decentralized scenario (refer Hoegh-Guldberg 2010c), and technological development is a mixed bag with little cross-fertilization between regions, and relatively weak trends towards renewable technology, energy efficiency, and environmentally sound developments of forestry and land management (refer Hoegh-Guldberg 2010d).

7.4.4 LINKING THE PRESENT TO THE STORYLINE

A2 could develop if a double-dipping financial crisis drags on into the mid to late 2010s, effectively crippling international cooperation and causing fragmentation into regional groups such as China succumbing to her internal problems, and the United States taking an increasingly isolationist course to the detriment of her major trading partners, southern neighbors, and global military and diplomatic leadership role. The impact of increasingly lethal terrorism and a feeling of futility about wars in Afghanistan and elsewhere may contribute to a general souring of international cooperation. Conflicts around the world would most likely escalate, especially if food security suffers in Africa and other vulnerable parts of the world.

International organizations, notably the United Nations, the IMF, World Bank and WTO, would probably lose much of the influence they have built up in a globalized world. The willingness of individual nations to fund the UN and its affiliated organizations has been an issue in the past, with the US falling short of its treaty-obligated contributions for seven years before President Obama pledged to resume the funding on his inauguration in January 2009. A developing trend towards an A2 scenario could well include nations withholding their funding obligations.

Ongoing climate change would cause further damage due to lower environmental protection control, generating added greenhouse gas emissions despite the economic slowdown. An A2 world could plausibly develop by the mid 2020s following a severe and protracted economic depression.

7.4.5 GLOBAL PATH TO 2100 AND BEYOND

Table 7.7 suggests that this scenario is a worst case, rivaling the fossil-intensive global A1FI variant and with less opportunity for remedial action in a poorer and more fragmented

Table 7.7: Unadjusted and adjusted World Product: A2						
	$ trillion at 1990 values			Proportion of unadjusted		Projection
	Unadjusted	"Most likely"	"Worst case"	"Most likely"	"Worst case"	$ trillion (1990)
1990	20.1	20.1	20.1	100%	100%	20.1
2010	31.9	31.9	31.9	100%	100%	31.9
2035	61.8	61.8	60.8	100%	98%	61.3
2050	81.6	81.2	73.8	100%	90%	77.5
2075	136.7	122.3	70.9	89%	52%	96.6
2100	242.8	168.4	40.8	69%	17%	104.6

Source: See Hoegh-Guldberg (2010b). The low 2010 estimate is shared by three of five A2 versions in the source tables, implying a very low rate of assumed growth in the first decade of the century.

world. Using the model of economic constraints due to global warming (Hoegh-Guldberg 2010b, Figure 3), the most likely case may keep up with the unadjusted path until the middle of the century but it then falls increasingly behind. The worst case is economic collapse in the second half of the century to a level in 2100 that happens to coincide with the level to which scenario A1FI declines (Hoegh-Guldberg 2010b, Figure 5). It is also at about the same level in 2100 as the estimated world GDP in 2010 at constant 1990 prices, for a global population twice the size of the current one in the original scenario (a level unlikely to be realized as the worst-case A2 scenario plays out).

An unmitigated A2 scenario would spell further disaster if we were to look beyond 2100.

The unadjusted growth for some unexplained reason shows an acceleration in economic growth between 2050 and 2075 (+68%) and 2075-2100 (+78%). Figure 5 in Hoegh-Guldberg (2010b) shows the scenario to grow at a more irregular pattern from decade to decade than the other scenarios. This looks dubious but the most recent update still showed the irregularities. In any case, the actual world economic product would be considerably less than the unadjusted projection if the assumptions for Table 7.7 are correct.

7.4.6 The United States in an A2 context

The dominant scenario according to Murphy (2007) in a regionalized economic world would be the impact of city-state economies which might deliver the upper end of a worldwide competitive situation that would see city-state powers elsewhere starting to compete for domination, perhaps either in cooperation or in competition with huge corporations. The net result (even within the US) would almost certainly be escalating conflict, aggravated as the world runs into growth constraints. The United States would most likely lose power and would be less likely, and able, to exercise its ability to resolve conflicts.

7.4.7 Zooming in on the Florida Keys

Some of what is written under A1 (Section 7.2.7) applies here as well. But the situation is worse under A2, which appears to be one to be most strenuously avoided. That goes for the world, for the United States, and for the Keys. One factor would be real estate values, which would be lower than in A1. Any environmentally friendly legislation would be gone, and the Keys probably abandoned as a lost cause (the projected 13,000 inhabitants in 2100 may be either very rich or quite poor). It is unclear where a doubled population would find room in

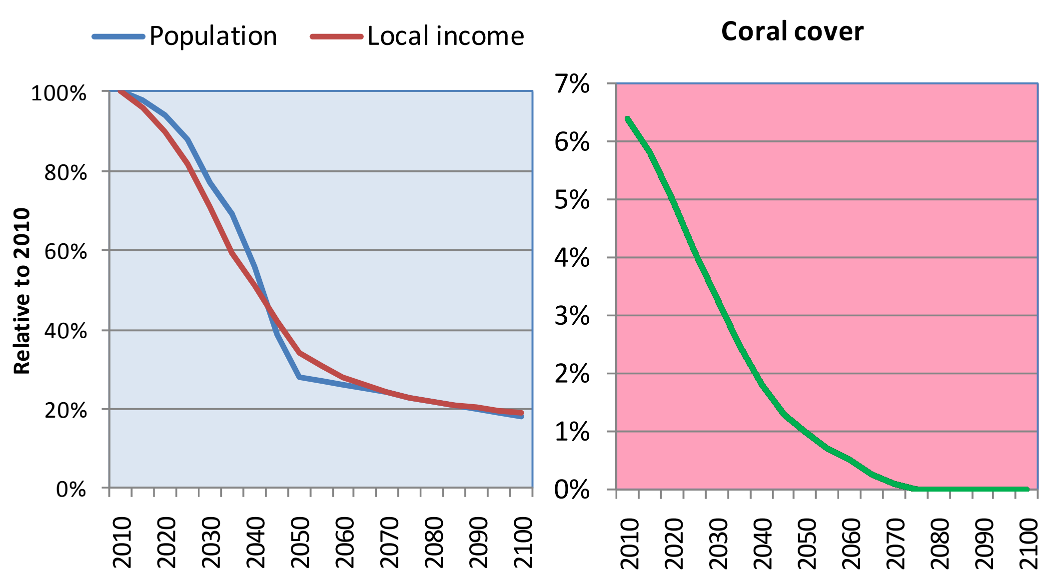
Florida, as estimated by Zwick and Carr (2006), as sea levels keep rising not just in the Keys but flooding Miami and surrounding urban areas as well, as well as other parts of the State.

The projected reduction of the Keys population to 13,000, with 82% inundation, and total income reduced to 19% of the level in 2010, is shown in Table 7.8. Any remaining coral cover will disappear by 2075. All four variables represent a case worse than the A1 scenario.

Table 7.8: Global and local projections for Scenario A2

Scenario A2	2010	2035	2050	2075	2100
Global temperature increase (°C)	0.8	2.2	3.2	3.8	4.4
Global sea-level rise (cm)	-	16	44	70	105
Global ocean acidification (pH)	8.1	8.0	7.9	7.8	7.7
Annual world GDP change	3.0%	2.6%	1.6%	0.9%	0.3%
Keys population	72,000	49,700	20,200	16,600	13,000
Population relative to 2010	100%	69%	28%	23%	18%
Keys coral cover	6.4%	2.5%	1.0%	0.0%	0.0%
Coral cover relative to 2010	100%	39%	16%	0%	0%
Keys area remaining	100%	69%	28%	23%	18%
Value of Keys area remaining	100%	79%	53%	45%	37%
Keys income relative to 2010	100%	59%	34%	23%	19%

Figure 7.9: Scenario A2, Florida Keys



7.5 B2: Regional environmental focus

7.5.1 The IPCC storyline

The B2 world is one of increased concern for environmental and social sustainability compared to the A2 storyline. Increasingly, government policies and business strategies at the national and local levels are influenced by environmentally aware citizens, with a trend toward local self-reliance and stronger communities. International institutions decline in importance, with a shift toward local and regional decision-making structures and institutions. Human welfare, equality, and environmental protection all have high priority, and they are addressed through community-based social solutions in addition to technical solutions, although implementation rates vary across regions.

Like the other scenario families, the B2 scenario family includes futures that can be seen as positive or negative. While the B2 storyline is basically neutral, a scenario from 1990 clearly paints a positive world with emphasis on decentralized governments and strong interpersonal relationships. In a 1995 scenario, values are only shared within small competing groups, which results in a decentralized world of tribes, clans, families, networks, and gangs. The IIASA-WEC "Middle Course" scenario from 1998, with slow removal of trade barriers, may also be grouped in this family. On the positive side, this storyline appears to be consistent with current institutional frameworks in the world and with the current technology dynamics. On the negative side is the relatively slow rate of development in general, but particularly in the currently developing parts of the world.

Education and welfare programs are pursued widely, which reduces mortality and, to a lesser extent, fertility. The population reaches about 10 billion people by 2100, consistent with both the UN and IIASA median projections [produced in 1996]. Income per capita grows at an intermediate rate to reach about US$12,000 by 2050. By 2100 the global economy might expand to reach some US$250 trillion. International income differences decrease, although not as rapidly as in storylines of higher global convergence. Local inequity is reduced considerably through the development of stronger community-support networks.

Generally, high educational levels promote both development and environmental protection. Indeed, environmental protection is one of the few truly international common priorities that remain in B2. However, strategies to address global environmental challenges are not of a central priority and are thus less successful compared to local and regional environmental response strategies. The governments have difficulty designing and implementing agreements that combine global environmental protection, even when this could be associated with mutual economic benefits.

The B2 storyline presents a particularly favorable climate for community initiative and social innovation, especially in view of the high educational levels. Technological frontiers are pushed less than they are in A1 and B1, and innovations are also regionally more heterogeneous. Globally, investment in energy R&D continues its current declining trend, and mechanisms for international diffusion of technology and know-how remain weaker than in scenarios A1 and B1 (but higher than in A2). Some regions with rapid economic development and limited natural resources place particular emphasis on technology development and bilateral cooperation. Technical change is therefore uneven. The energy intensity of GDP declines at about 1% per year, in line with the average historical experience since 1800.

Land-use management becomes better integrated at the local level in the B2 world. Urban and transport infrastructure is a particular focus of community innovation, and contributes to a low level of car dependence and less urban sprawl. An emphasis on food self-reliance contributes to a shift in dietary patterns toward local products, with relatively low meat consumption in countries with high population densities.

Energy systems differ from region to region, depending on the availability of natural resources. The need to use energy and other resources more efficiently spurs the development of less carbon-intensive technology in some regions. Environment policy cooperation at the regional level leads to success in the management of some trans-boundary environmental problems, such as acidification caused by sulfur dioxide (SO_2), especially to sustain regional self-reliance in agricultural production. Regional cooperation also results in lower emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which reduce the incidence of elevated tropospheric ozone levels. Although globally the energy system remains predominantly hydrocarbon-based to 2100, a gradual transition occurs away from the current share of fossil resources in world energy supply, with a corresponding reduction in carbon intensity.

7.5.2 Would this scenario story have been written differently in 2010?

The defining feature of B2 is environmental awareness, encouraged in strong, well-educated and cohesive communities putting high priority on equality, health, and environmental protection. As distinct from one of its precursor scenarios, B2 does not mean societies dissolving into networks of tribes, clans, families, networks, and gangs, though apart from antisocial gangs these may help holding these societies together.

The regional structure, however, is big enough to allow for policies on equality, health and the environment to be successful, and there is sufficient communication across the globe to allow regions to cooperate on environmental protection, even though solutions differ at local and regional level. Regional size is not defined but might cover interlocking regional networks of everything from “the Indian subcontinent” through the State of Uttar Pradesh to one of its 70 districts ranging from the capital Lucknow through village districts. The glue binding them together here remains the defining feature of environmental awareness, coupled with strong community values.

The role of technology in a B2 scenario written today would probably be viewed more positively than in the original, where it was seen as limiting economic growth with falling R&D expenditure and constraints on the international diffusion of technology and knowhow. It is also plausible in this well-educated world that the increasing threat from global climate change which has become apparent since 2000 has resulted in higher priority to strategies to address global environmental challenges – given that environmental protection was already one of the few truly international common priorities in the original B2 scenario.

Diffusion rates have increased greatly since B2 was written (Burns et al. 2008, Hoegh-Guldberg 2010d), and there are signs that real innovation (as distinct from diffusion of existing technologies) is spreading beyond a few rich countries, to China, India, Brazil and elsewhere.

In contrast to the regionalized economic development scenario, A2, technological trends may be at play which could be successful at regional B2 level. B2 might benefit more from the fact that cell phones are rapidly permeating some of the poorest countries in Sub-Saharan Africa, to be followed by cheap Internet-connected computers (Standage 2009). The spread of Grameen Bank in Bangladesh and the internationalization of the concept through the Grameen Foundation is also based on strong community values. Furthermore, renewable energy technologies such as solar photovoltaics are proving beneficial and affordable at village level, and existing technologies aimed at improving biologically diverse agricultural methods and simultaneously helping trees and plants regain their role as CO_2 sinks are also highly applicable at local level. (See Hoegh-Guldberg 2010d for detail.)

This emphasis on small-scale technologies, which fits in with the strongly community-based approach in the B2 scenario, does not preclude large-scale projects. Some of the largest cities in the world are in Africa, and further urban growth will necessitate large-scale energy plants. A B2 regime would be sympathetic to compact urban design and other energy-saving developments, but large-scale solar and other renewable-energy plants will still be required.

The power and inflexibility of big government and big business have probably declined in a regionalized (de-globalized) world, and the storyline itself is explicit that concerned citizens have a bigger say. Finally, a continuous global population increase to over 10 billion by 2100 now looks excessive, given the reduction in total fertility rates across the world and given the high educational level in the B2 world. Reaching 9 billion by 2050 may be almost inevitable, but some reduction may be realistic in the second half of the century.

Even before considering the evidence in the next section, we may find a more positive storyline to tell in the B2 quadrant of the tree diagram. Based on the greater urgency in dealing with climate change this includes the final statement in the storyline that energy supplies remain predominantly hydrocarbon-based until 2100 (increasingly favoring gas over oil). A rewritten B2 storyline might respond plausibly to the increased urgency to phase out fossil fuels at a faster rate (while still favoring gas over oil during the transition process), and the recent and current growth in renewable technologies that is becoming evident.

7.5.3 Current physical, economic and technological influences

The line taken by Hoegh-Guldberg (2010a), tracing the escalating science-based demands for average global warming to remain below $2^{O}C$ above pre-industrial levels (and retaining atmospheric CO_2 levels at or below 350 ppm), would not put the original B2 scenario in as good a position as the global environmental scenario B1. But an updated B2 story may be closer.

As in B1 but with a more diverse pattern, economic policy will be sensitive to the economics of climate change, and will recognize and manage the “animal spirits” in the financial and commercial sectors (Hoegh-Guldberg 2010b). In a world where community values play a bigger role, economics is also likely to adopt a more holistic approach, influenced by other social sciences, biology and other components inspired by complexity theory (Hoegh-Guldberg 2010c).

While there will still be a need for large renewable technology solutions, these are unlikely to be dominated by environmentally hazardous schemes like covering large parts of the Sahara desert with photovoltaic elements or concentrated solar power (CSP) plants to fill European power needs. Genetically modified crops will be needed for food security reasons, and will be encouraged by large biotech companies seeing an social and even financial advantage in giving preferential treatment to farmers in poor nations (*The Economist* 2009).

Generally, however, agricultural technologies aimed at combining biodiversity with productivity would appeal most in this strongly community-based scenario. Hoegh-Guldberg

(2010d) names a number of such technologies, for example Vendana Shiva's "nine crops" program which aims specifically at improving biodiversity through agricultural practices in India (Shiva 2005). It fits in well with the diversity in this regionalized scenario that there is a wide range of possible solutions to fit different agricultural conditions.

The B2 story, as written, shares the position of lowest economic growth with the regionalized economic growth scenario A2. In the best case (Hoegh-Guldberg 2010b, Figure 3), B2 grows continuously to $200+ trillion, and the "most likely" case by almost as much. However, the worst case has B2 at a maximum of $150 trillion in 2080, following by decline, presumably due to increasing population pressures towards the end of the century.

This contrasts with the B1 scenario, which shows continuous economic growth to about $270 trillion, but a rewritten B2 scenario may get closer, perhaps halfway between B1 and the original B2. Moreover, there are features in B2, notably the strong community spirit and commitment to local and regional causes, that could well be copied into an enhanced B1 scenario.

7.5.4 LINKING THE PRESENT TO THE STORYLINE

An interruption of the globalization trend during the 2010s may have similar economic causes to those postulated for the regional growth-driven A2, but the reaction will be different. Though the world economy meets protracted difficulties in recovering from recession, the reaction of its citizenry is different.

Some spectacular performances by Mother Nature during the early 2010s in the heat wave, drought, monsoon, and hurricane departments, help convince a majority across the planet that urgent action is needed. The Deepwater Horizon oil spill in 2010 also made its mark, attracting attention to the plight of the largest coastal wetlands in the nation, in Louisiana, and at a basic emotional level through images of distressed pelicans drenched in oil. The B2 world, as described, also has closer cooperation between regions than A2. In particular, the climate change talks continue in a constructive vein, despite continued lackluster economic growth. At COP-17 in December 2011 formal agreement is reached to move towards drastic reduction in greenhouse gas emissions consistent with an eventual level of <350 ppm atmospheric CO_2, which became the science-based norm in 2009.

B2 is another scenario that should be significantly rewritten compared with its treatment in the decade-old Third Assessment Report, but in contrast to A2 it is now viewed more positively. Technological development and diffusion in particular are likely to be faster, and will favor the development of many "small" technologies benefiting local communities, as well as the replacement of fossil energy with renewables long before the end of the century, as distinct from the original B2 scenario. These technologies will coexist with larger projects needed for the generation of power and presumably for the development of green biotech schemes. The resulting mixed pattern of mainly renewable small- and large-scale technologies should be clearly visible in this scenario by the mid 2020s.

7.5.5 GLOBAL PATH TO 2100 AND BEYOND

The top panel of Table 7.9 shows the original B2 scenario in its unadjusted form, and after being subjected to the constraints caused by a rise of global temperatures according to the model in Hoegh-Guldberg (2010b). The growth in the unadjusted model is slightly lower than for A2, but irregularities in the latter must be treated with some caution, as noted under A2.

Even before being adjusted upwards, the "most likely" case taking global warming into account compares well with the unadjusted case: it comes within 10% even in 2100. In the worst case, the global economy starts to decline in the last quarter century, to reach only 56% of the unadjusted scenario path in 2100.

Table 7.9: Unadjusted and adjusted World Product: B2

	$ trillion at 1990 values			Proportion of unadjusted		Projection
	Unadjusted	"Most likely"	"Worst case"	"Most likely"	"Worst case"	$ trillion (1990)
As per original scenario in 2000						
1990	20.9	20.9	20.9	100%	100%	20.9
2010	38.6	38.6	38.6	100%	100%	38.6
2035	75.8	75.8	75.8	100%	100%	75.8
2050	109.5	109.5	107.5	100%	98%	108.5
2075	173.9	169.5	146.7	97%	84%	158.1
2100	234.9	212.5	132.4	90%	56%	172.5
Adjusted to new estimate in 2009 (average of original estimate and B1)						
1990	20.9	20.9	20.9	100%	100%	20.9
2010	38.6	38.6	38.6	100%	100%	38.6
2035	81.4	81.4	81.4	100%	100%	81.4
2050	122.6	122.6	121.6	100%	99%	122.1
2075	201.5	199.3	180.7	99%	90%	190.0
2100	281.7	265.9	201.4	94%	72%	233.7

Source: See Hoegh-Guldberg (2010b)

B2 should be increased in the light of new knowledge since the scenarios were built. The lower panel of Table 7.9 assumes that the difference between B1 and B2 is cut in half. According to Hoegh-Guldberg (2010b, Table 1), the best, most likely and worst cases for B2 are +1.7^{O}C, +2.4^{O}C, and +3.8^{O}C, compared with +1.1^{O}C, +1.8^{O}C, and +2.9^{O}C for B1. The revised B2 therefore uses +1.4^{O}C as best, +2.1^{O}C as most likely, and +3.3^{O}C as worst case. The unadjusted path has also been increased by half the difference between B1 and the original B2. B2 therefore now fares even better in the most likely case, losing only 6% compared with the new unadjusted path. The worst case loses 28% by 2100, mainly in the last quarter of the century. While even this case shows continued growth, it is getting close to zero by 2100, auguring badly for the next century if allowed to persist.

Greenhouse gas levels will be too high under the adjusted B2 scenario, though not much more so than B1 judging from Table 1 (Hoegh-Guldberg 2010b). The estimated level of atmospheric CO_2 in 2100 in the unadjusted B2 scenario is 616 ppm, compared with 545 ppm for B1. This suggests about 570 ppm for the revised B2.

These figures are illustrative only. Nevertheless, the update is probably more realistic than the original scenario, given the new developments.

If the world is to reduce CO_2 levels quickly towards 350 ppm (and other greenhouse gases in proportion), B1 remains the most promising scenario for the 21st century and beyond.

However, B2 has some attractive features, such as the engagement of a large number of actors at different regional levels, which might be helpful in reinforcing the B1 scenario.

Encouragement of a strong local community spirit would be very important for the effort to promote all relevant technologies to achieve the 350 ppm CO_2 target. Such a community spirit exists in many places already, including the Florida Keys. It won't happen, however, if the current upward trend in the number of climate deniers continues. The need to get a large majority of the world's population to understand the climate change threat and become actively engaged is urgent and critical for success – and perhaps more difficult to achieve than before based on the experience during 2009.

7.5.6 The United States in a B2 context

The best hope for the United States would be that the community spirit outlined in the previous sections would be reflected here. This community spirit would not eliminate the risks of factors such as sea-level rise, but it would generate a momentum towards consciousness of the risks and taking effective action. The spirit would permeate everything from national to local effort, spearheaded by those regions most at risk, including the Florida Keys. The advocacy at that level, evidenced by local organizations such as the Sanctuary Friends Foundation of the Florida Keys (SFFFK) and Green Living and Energy Education (GLEE), will prove to be of vital importance in the promotion.

7.5.7 Zooming in on the Florida Keys

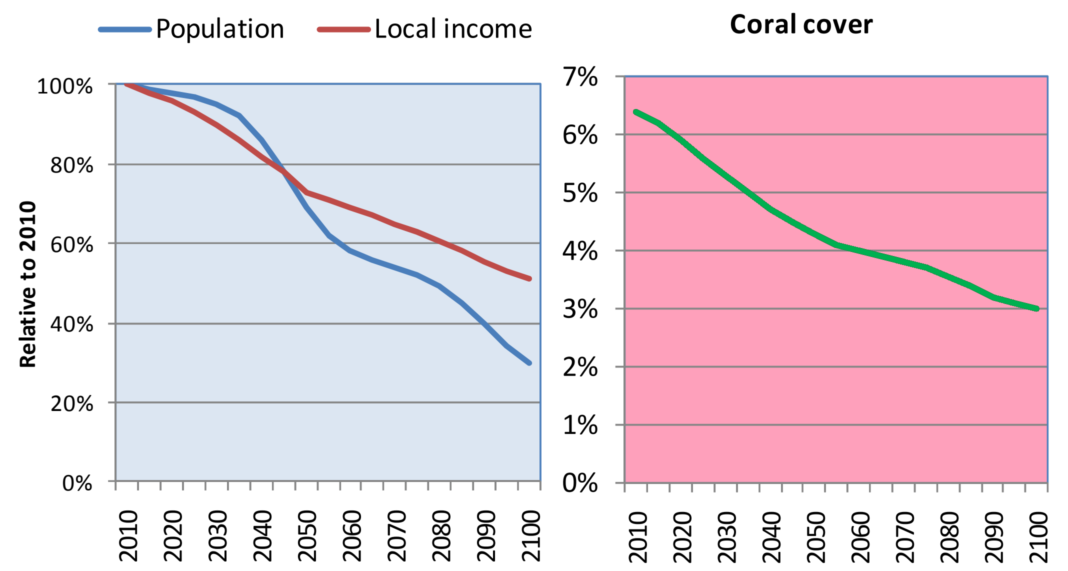
While not as positive as B1, the limited information available suggests that the community-based support and environmental orientation makes this the second-most positive scenario (Table 7.10). It contrasts favorably with the bleak local prospects of the economic growth-based regionalized scenario, A2, to demonstrate that social cohesion and a strong sense of community and respect for the environment will go a long way, given that B2 would be judged more favorably today than when it was created. It assumes that the work on coral reef resilience will continue under an active and strong sanctuary management supported by other organizations and groups, and that the natural land-based and historic environment will be preserved to the maximum extent in the face of the rising sea level, all actively backed by the community.

Table 7.10: Global and local projections for Scenario B2

Scenario B2	2010	2035	2050	2075	2100
Global temperature increase (^oC)	0.8	1.6	2.2	2.6	3.0
Global sea-level rise (cm)	-	7	16	25	37
Global ocean acidification (pH)	8.10	8.05	8.00	7.95	7.90
Annual world GDP change	3.0%	3.0%	2.7%	1.8%	0.8%
Keys population	72,000	66,200	49,700	36,700	21,600
Population relative to 2010	100%	92%	69%	51%	30%
Keys coral cover	6.4%	5.0%	4.3%	3.7%	3.0%
Coral cover relative to 2010	100%	78%	67%	58%	47%
Keys area remaining	100%	92%	69%	51%	30%
Value of Keys area remaining	100%	94%	79%	68%	56%
Keys income relative to 2010	100%	86%	73%	63%	51%

There will be a viable tourist industry based on Key West's historic attractions and the nature-based activities of the Keys, and local residents will dominate, rather than outsiders leasing or owning condominiums and time-share accommodation.

Figure 7.10: Scenario B2, Florida Keys



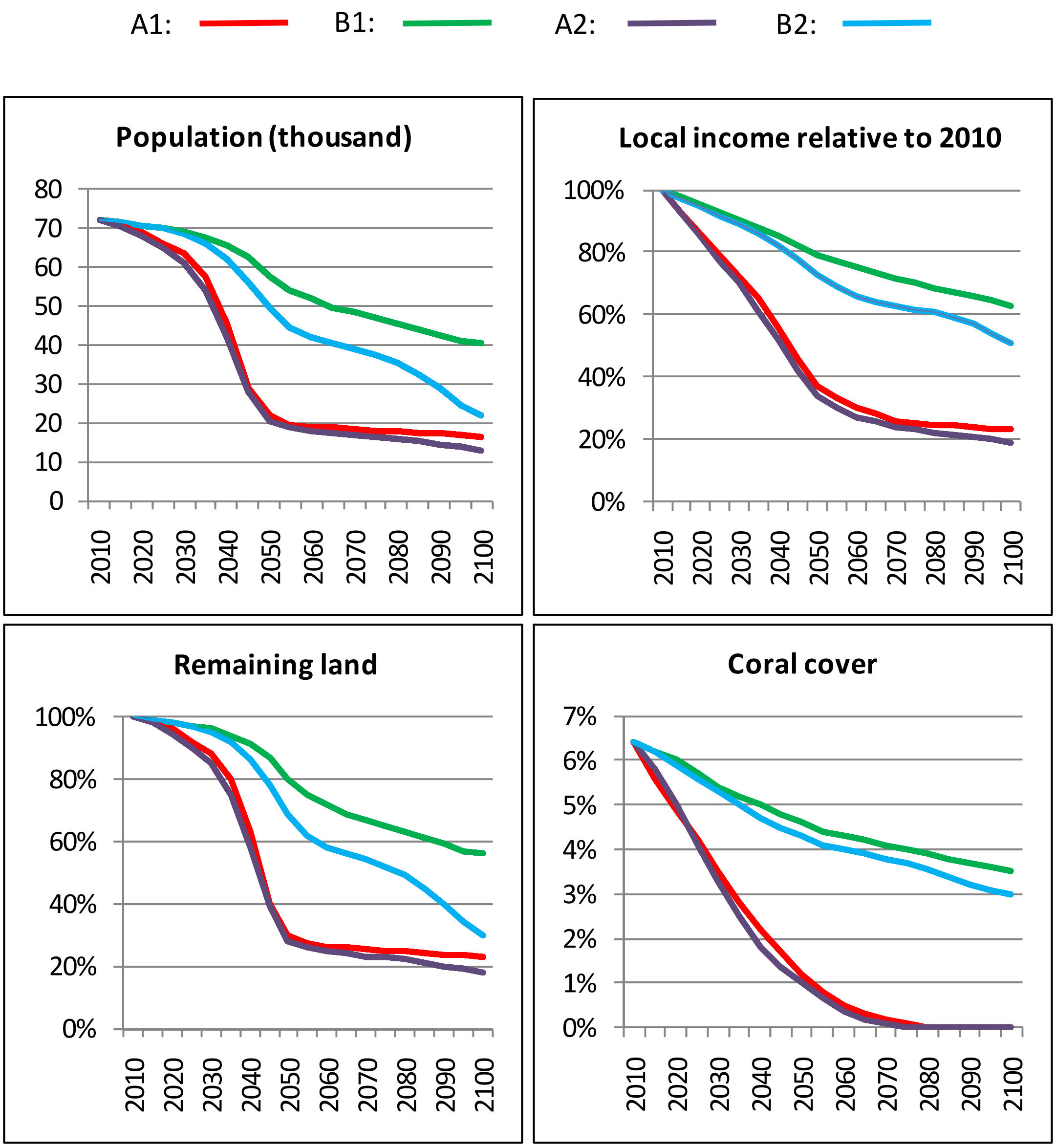
One observation in Table 7.10 looks surprising but it is based on TNC's empirical work on sea-level rise (Bergh 2009, as reflected in Section 7.1.5 in Figure 7.5). Figure 7.10 shows two phases in the inundation process: between 2035 and 2050, and again after 2075. As a result, the remaining area and the population falls to 30% of the 2010 level by the end of the century, compared with 56% for B1. The inference is that it is vital for the Florida Keys to secure a global environmentally benign scenario like B1 as soon as possible. The longer "business-as-usual" behavior drags on, the greater the risk that even the best-case global scenario will be insufficient to save substantial parts of the Keys from the worst excesses of sea-level rise beyond the end of the 21st century.

7.6 COMPARISON

Figure 7.11 (overleaf) shows the trajectories for all four scenarios on one chart. The indicators are population (number of persons rather than the decline compared to 2010 shown on the previous graphs) and coral cover.

The scenarios form two groups: A1 and A2 are the most unfavorable, B1 and B2 the most favorable (with the proviso mentioned in the previous section that B2 shows a more unfavorable population trend after 2075 related to the elevation pattern of the Keys). The regional scenario version is less favorable than the globalized version for both sets. The margin, however, is still generally wide between the regionalized environmental scenario, B2, and the "balanced" renewable/fossil version of the global economic scenario, A1B.

Chart 11: Comparative scenarios, Florida Keys



8 Policy recommendations

All policy recommendations are those of the author and are not necessarily endorsed by NOAA.

8.1 Guidance from other research

The policy recommendations represent the ultimate outcome of this project, following the approach in the report on the Great Barrier Reef which provided the model. The provision of policy recommendations was a requirement (Hoegh-Guldberg 2005, p 7 and elsewhere).

Other reports are quoted in support, bringing different perspectives to the final recommendations. The first is a study of the Coral Triangle in Southeast Asia (Hoegh-Guldberg et al. 2009). The lead author was Ove Hoegh-Guldberg with co-authors including this writer (economics and scenarios) and Lara Hansen, chief scientist and executive director of EcoAdapt, who drafted the policy recommendations. With her colleague Alessandra Score, formerly WWF's Florida program marine conservation specialist, she adapted a set of annotated Coral Triangle recommendations to suit the Florida Keys. Their insights are essential, generally agreed upon, and gratefully acknowledged. Adapted to the Keys, they qualify as a prime set of final recommendations.

The other selected reports are the second US Global Change Research Report (Karl et al. 2009) and the TNC report on sea-level rise in the Keys (Bergh 2009). Concluding comments and an attempted synthesis follow at the end of Chapter 8.

8.1.1 Adaptability of Coral Triangle issues to the Florida Keys

The Coral Triangle covers some of the most prolific and biologically diverse coral reefs in the world, located off Eastern Indonesia, Sabah, the Philippines, Timor Leste, Papua New Guinea, and the Solomon Islands (Hoegh-Guldberg et al. 2009). The recommendations of that report are truly policy-related, from global to local level.

The list below shows each Coral Triangle recommendation adapted to incorporate Lara Hansen's and Alex Score's observations relating to the Florida Keys (with a few comments based on the author's own experience). The observations form a very important step toward a final set of recommendations because of their local insight. Each item in the Coral Triangle list was edited but remains easily recognizable compared to the original one, shown at the end of the executive summary of the Coral Triangle report. The agreement is striking between the issues evoked about the largest and most biologically diverse coral reef system in the developing world, and the Florida Keys, located in a vastly different physical and socioeconomic setting.

It is also implicit in the amended recommendations that the Keys form a "higher-order" ecosystem (discussed in Chapter 3.3) – all component ecosystems and socioeconomic structures are interrelated and subject to threat if the total Keys system is threatened.

The amended and annotated list of recommendations for the Keys follows:

1. *Create a binding international agreement to reduce the rate and extent of climate change.*

Emissions should peak no later than 2020 (preferably by 2015), and global warming should be limited to well below $2^{O}C$ above pre-industrial temperatures by 2100, to keep atmospheric CO_2 below 350 ppm. This will require steep global cuts in emissions that are at least 80% below 1990 levels by 2050. Inherent to this recommendation is the creation of an aggregate group reduction target for developed countries of 40% below 1990 levels by 2020, and a reduction from emission levels for developing countries of at least 30% by 2020.

2. *Take immediate action to establish national, state and local county targets and plans to meet these commitments such that the international agreement can be achieved.*

   This report shows that the Florida Keys have a great deal at stake if climate change continues unchecked, more than practically any other part of the nation. Monroe County and other authorities must become part of the solution and must do this expeditiously. This can start with meeting targets at the local county level, while simultaneously acting as a major voice pushing for state and national reductions (directly and in cooperation with other local governments). Lag-times and non-linear responses in the climate system mean that for every day we wait to take action, the problem becomes dramatically more difficult and costly to address successfully. This will hit Floridians at home – personally, socially and economically.

3. *Pursue the establishment of integrated coastal and marine zone management across the region to reverse the decline of the health of coastal ecosystems*.

   This should include a partnership between the federal, state, and local governments across jurisdictional boundaries for the implementation of policies that ideally eliminate further coastal development, reduce pollution, expand marine protected areas, regulate fishing pressures and abolish destructive practices. The recommendation harmonizes with the existing integrated coastal management philosophy of the FKNMS which is based on cooperation with multiple local, state and national jurisdictions. It is important that these actions do not aim to restore or protect ecosystems for past conditions, rather they must prepare for conditions under a changing climate that allow for migration and adaptation.

4. *Support the establishment of a Florida Keys "climate change fund" to meet the adaptation needs of this sensitive and vulnerable critical ecosystem*.

   While some of the cost of adapting to climate change can be met by redirecting current resources that are being used in a manner that is vulnerable to climate change, the growing challenge of climate change will result in new and increasing costs. Funds will be required to meet these costs given that the hardship caused by the climate change in Florida will be felt disproportionately in the Florida Keys. National and state funds will be necessary to meet these challenges. Funds for ecosystems and for human communities will both be needed and the efficacy of each will rely on coordination between the two.

5. *Build adjustable financial mechanisms into national and state budgeting to help cover the increasing costs of adaptation to climate change in the State of Florida*.

   Climate change will require not only new funds, but also a reassessment of current spending so that funds are spent in ways that are "climate-smart", in other words on efforts that are resilient to climate change. Every effort should be made to avoid spending funds and taking actions that exacerbate the problem of climate change, such as building new coal-fired plants, oil drilling off the coasts of Florida and continuing to develop and insure infrastructure along Florida's vulnerable coast.

(This was written before President Obama's announcement, on March 31, 2010, to allow oil and gas exploration to "responsibly expand'' drilling in new areas like the eastern Gulf of Mexico, 125 miles off Florida's coast, as well as in the Atlantic as far south as Central Florida. It was consequently also written before disaster hit BP's Deepwater Horizon operation in May. The above recommendation remains unaltered.)

6. *Integrate resource protection into the Florida Keys development master plans to provide robust holistic protection in the face of climate change*.

   Adaptation plans cannot be developed on a sector-by-sector basis. Doing so risks creating problems such as adaptation being effective against one issue but maladaptive against another. It will be important to plan holistically and create governance structures that can support, implement and monitor these efforts.

7. *Build the socio-ecological resilience of coastal ecosystems and develop stakeholder and community engagement processes for communities to improve their ability to survive climate change impacts*.

   Involving coastal people and communities in planning provides greater stability and efficacy for solutions to social and ecological challenges within the Florida Keys. Fundamentally, it will be local knowledge that generates innovative adaptation strategies which may prove most successful. Reducing the influence of local stress factors on coastal ecosystems makes them able to better survive climate change impacts. Protecting the diversity of components (communities, populations, and species) under the guidance and actions of local people strengthens the resolve of these systems in the face of climate change. As described in Section 4.4, the Florida Keys are fortunate to already have a strong community understanding of the issues, but it is important to encourage even more people to participate.

8. *Build capacity to engage in planning for climate change. Climate change planning, both mitigation and adaptation, will require that we educate current and future practitioners, as well as the concerned constituencies*.

   Mechanisms must be created to develop current resource managers and planners so that they can immediately implement these new approaches. As the problem of climate change is not one that we will be solving in this generation, planning and responses to climate change will be iterative as the target continues to move over the coming centuries. Therefore, it will also be necessary to develop training for future capacity through education in academic settings. Informed stakeholder and community engagement is at the core of successful adaptation, so in addition to professionals and students, civil society must be given access to the information they need to understand and respond to climate change. In fact, developing a trained and informed community in the Florida Keys could develop a stronger sense of community and camaraderie in the Keys which will be needed to endure this major challenge.

9. *Integrate climate change adaptation into all conservation and development efforts at the local, national and regional levels and revise current plans for their robustness in the face of climate change*.

   "Business-as-usual" conservation and development will not achieve success. The new mode of action requires integration between conservation and development, and the realization that many past approaches are no longer effective due to the impacts of climate change. The Florida Keys are inherently vulnerable to climate change. Their best chance, assuming that global action is taken to reduce greenhouse gas emissions and slow the rate and extent of climate change, is to increase the resilience of the system as a whole. No decision should be made in the Florida Keys that is not "climate smart".

10. *Focus adaptation throughout Florida on playing a role in economic stimulus, especially in job creation and financial mobilization. Incentives can also be in new "climate smart" development*. (Note: The recommendation could be extended to cover all States in the Southeast, or nationally.)

    Private-public sector incentive schemes, regional/state arrangements and investment partnerships (e.g. national insurance reform and special-access loan schemes) need to better incorporate risk management and adaptation strategies to reduce investment risk and maintain positive financial conditions.

In summary, the adapted Coral Triangle recommendations fall roughly into three groups:

- *Internationally*, it is urgent to achieve binding international agreement on emissions cuts, supported on national and regional targets in all countries (items 1-2)
- *Locally* (supported at state and national level), integrated coastal and marine management is essential, including funding for the Keys as an area at particular risk, holistic planning and building both socioeconomic and ecological resilience. Educate to develop a trained and informed community to better mitigate and adapt to climate change (items 3-8)
- *At all levels from local to national*, adapt existing conservation and development efforts for climate change robustness, and plan for adaptation efforts to play a role in economic stimulus and achieve "climate-smart" development (items 9-10).

8.1.2 THE GLOBAL CHANGE RESEARCH PROGRAM REPORT

Being the first report since 2000 to provide an extensive evaluation of regional climate change impacts on the United States, its recommendations are pertinent to our own policy advice. They present another inspiring, useful and relevant list in their own right. Although there is some overlap, the perspective differs from the adapted Coral Triangle recommendations, by advocating a more influential and stronger climate science as a prerequisite to tackle policy and advocacy issues with maximum conviction and certainty.

Both sets of viewpoints are legitimate and necessary. Scientific knowledge is essential but incomplete; scientists are painfully aware of the uncertainty that still attach to climate models, especially as it plays into the hand of climate change deniers among the public, politicians, and business, whether their views are due to ignorance or vested interests. This is an growing cause for concern as climate change becomes more ominous but still appears to many non-scientists to be decades away.

The recommendations are reproduced below with essential annotations from the accompanying text (for the full version refer Karl et al. 2009, pp 153-156):

1. *Expand our understanding of climate change impacts* on ecosystems, economic systems, human health, and the built environment. Ecosystem changes include changes in the chemistry of the atmosphere and precipitation, vegetation patterns, growing season length, plant productivity, animal species distributions, and the frequency and severity of pest outbreaks and fires. In the marine environment, changes include the health of corals and other organisms suffering from temperature stress and ocean acidification. In addition to observations, large-scale whole-ecosystem experiments are essential for improving projections of impacts, especially for ecosystems risking massive change due to the crossing of thresholds or tipping points.
2. *Refine ability to project climate change, including extreme events, at local scale*. Climate change is a global issue but has a great deal of regional variability. There is an indisputable need to improve understanding of climate system effects at regional scales, which are often the scales of decision making in society. "Continued development of improved, higher resolution global climate models, increased computational capacity, extensive climate model experiments, and improved downscaling methods will increase the value of geographically specific climate projections for decision makers in government, business, and the general population." (p 154)
3. *Expand capacity to provide decision makers and the public with relevant information on climate change and its impacts*. There are significant data gaps, including damage cost. Services that provide reliable, well-documented, and easily used climate information should be made available to support users.
4. *Improve understanding of thresholds likely to lead to abrupt changes in climate or ecosystems.* There are key risks to society for which understanding is still quite limited such as thresholds leading to rapid changes in ice sheet dynamics, causing sea-level rise. The increasing concern about ocean acidification has created a need to establish acidity thresholds beyond which corals and other organisms, including those at the base of marine food chains, can no longer form shells for their body structure to survive.
5. *Improve understanding of the most effective ways to reduce the rate and magnitude of climate change, as well as unintended consequences of such activities.* Impacts of climate change are projected to be by far the largest and most rapid in scenarios in which greenhouse gas concentrations continue to grow rapidly. Additional research will help identify the desired mix of mitigation options necessary to control the rate and magnitude of climate change. Unintended consequences of mitigation options (such as competing use of land, water and other resources) need to be explored to help decision makers make better choices on possible trade-offs inherent in various mitigation strategies.
6. *Enhance understanding of how society can adapt to climate change.* Not enough is known on the potential cost of adaptation measures. "It is important to improve

> understanding of how to enhance society's capacity to adapt to a changing climate in the context of other environmental stresses. Interdisciplinary research on adaptation that takes into account the interconnectedness of the Earth system and the complex nature of the social, political, and economic environment in which adaptation decisions must be made would be central to this effort." (p 156)

In summary, these six recommendations concern how to remedy lack of scientific knowledge to allow the evidence to be presented as convincingly and unequivocally as possible. Scientifically, we don't know enough about the impact of climate change on ecosystems and human systems, how to project local climate change, the thresholds to abrupt climate change, and the systems controlling climate change and how to avoid unintended effects from mitigation options (items 1,2 4 and 5).

We are also short on information on damage and other costs, and the cost of adaptation in the context of other environmental stresses (items 3 and 6).

The second group is primarily about the cost of adapting to climate change, which would vary with local factors and therefore most amenable to a microeconomic approach.

8.1.3 STRATEGIES RELATED TO SEA-LEVEL RISE IN THE KEYS

Sea-level rise (SLR) is potentially the most serious effect of climate change in the Keys. Proactive response strategies will take two general forms: mitigation and adaptation. It is important to consider specific planning approaches proposed to mitigate against further sea-level rise, and adapt to it. This section is based on the concluding section of Chris Bergh's 2009 paper, which also showed, at least by implication, how everything in the Keys hangs together in a "super" or "higher-order" ecosystem.

Mitigation of the root causes of climate change and SLR must take place at every scale from the global to the local in order for the Florida Keys to experience any appreciable reduction in the local SLR

This includes International, national, and state agreements, municipal laws, and regulations and codes to address climate change mitigation. Monroe County's Green Initiatives Task Force and local government "green teams" play an increasing role in developing and tracking mitigation actions. The influence of community organizations is described in Section 4.4.

Mitigation activities notwithstanding, the Florida Keys will experience SLR-driven changes that will incrementally diminish the viability of terrestrial plants, animals and natural communities while creating new marine habitat of uncertain quality

Miami-Dade County's Climate Change Advisory Task Force recommends support for the Comprehensive Everglades Restoration Plan as a restored Everglades ecosystem will be better able to resist SLR-driven change and protect South Florida's freshwater supply. Examples of SLR adaptation planning by government entities are relatively few in the Florida Keys, but that is changing. The Fish and Wildlife Service is incorporating SLR estimates in its management planning, and the City of Key West is beginning to factor SLR into its engineering and construction decisions.

Ross et al. (2009) lay out a compelling argument for helping natural areas and ecosystems adapt to both the incremental long-term effects of SLR and acute disturbances such as storm surges and forest fires. Their approach calls for identification of "core areas" with the best chances of persistence during SLR, intensive management of core areas to minimize loss of biodiversity, and relocation of vulnerable species to less vulnerable areas.

Identifying core areas will not be as simple as choosing the highest ground, although elevation is a critical component. Other important components include representation of all habitat types and species; replication of core areas so the impact of a single unmanageable event, such as a severe storm surge, is less likely to damage all habitat or species occurrences; connectivity through biological corridors or other means; and effective management of core areas.

Managing for resilience and adaptation to SLR

The concept of resilience is central to the strategies to preserve ecosystems in the Florida Keys. Section 4.3 focuses on the Florida Reef Resilience Program to minimize human-induced stresses on local coral reefs. But resilience applies more generally: "Entire ecosystems, core areas, species populations, individual organisms, and even human communities with their built environment and industries all possess a measure of resilience that can be enhanced or degraded." (Bergh 2009, p 29)

"No regrets" strategies for managing Florida Keys natural areas for SLR

Several management strategies, which have been practiced in the Keys for decades, increase the resilience of natural areas and native species to SLR. These strategies include:

- Fire management of pine rock-land forests, found only in the Lower Keys, southern Miami-Dade County, the Bahamas and Caicos islands. These fire-dependent forest communities sustain a remarkably rich diversity of flora and fauna. Of the eleven Lower Keys supporting pine rocklands, five (Upper Sugarloaf, Cudjoe, Big Pine, No Name, and Little Pine) have sufficient acreage for management in a prescribed fire context (Bergh and Wisby 1996). The pine in question is the south Florida slash pine (*Pinus ellioti* var. *densa*).
- Management of invasive exotic species that degrade natural areas by directly competing with native species that have life history requirements similar to those of the invader. *Casuarina* species known locally as Australian pine destabilize dunes and other coastal habitats that are the front line of natural defense against storm surges and coastal erosion which will be exacerbated by SLR. Salt-tolerant species including the Asian *Colubrina asiatica* and *Scaevola sericea* which invaded the US mainland from Hawaii take over from less salt-tolerant local species.
- Restoration of Florida Keys wetland habitats. In the course of developing the Florida Keys, people filled many freshwater, brackish and saltwater wetlands, drained others via ditching, and fragmented others in the course of constructing raised roadbeds. Freshwater wetlands are therefore among the rarest habitat types in the Keys and they are critically important to many wildlife species.

Problems and promises of off-site conservation approaches

Resilience-based planning and management for terrestrial systems and species will not eliminate the eventual need for implementation of "ex-situ" or off-site conservation strategies, but they will help stave off that need. Ex-situ strategies, while perhaps necessary to prevent extinction of species and subspecies endemic to the Florida Keys, are fraught with uncertainty and risk (and they won't save the Keys from inundation). Long-term monitoring of any species introduced into a new habitat, and their impacts on their new habitat and native species, must be part of the plan.

Managing today for tomorrow's marine ecosystem

The following statement would apply fully to a "business-as-usual" scenario although losses are also expected in more benign situations: "Intensive management of core areas, while appropriate and necessary, ultimately will not prevent the wholesale transformation of terrestrial habitat into new marine habitat under current SLR projections. The Florida Keys — including core areas which will hold out the longest, particularly if they are intensively managed — will become marine habitat and are likely to remain marine habitat for many millennia thereafter. In light of this, intensive management should not include activities that will result in compromised marine habitat quality in the future." (Bergh 2009, p 31)

Conclusion

"Sea-level rise is real now and all indications are that the rate of rise will accelerate in the coming decades. Unlike the acute impacts of a hurricane, which the Florida Keys have historically withstood or recovered from, the impacts wrought by SLR will be permanent. Mitigation of the root causes of climate change and sea-level rise may slow or reduce its impact, but significant change is inevitable. Natural areas, native species and human communities will have no choice but to adapt. Decisions made today will influence, sometimes profoundly, the ability of people and nature to adapt to SLR in the future." (p 32)

Summary

Research into sea-level rise is central to the understanding of the potential impact of climate change in the Keys. It adds an important dimension to the proposed policy recommendations in the two previous sections, which were based on the Coral Triangle study and the second report of the US Global Change Research Program, respectively.

In summary, climate change, including its impact on sea-level rise, is determined by global forces but mitigation must take place at every level down to local regulations and recommendations by "green teams". Change driven by sea-level rise will happen regardless of mitigation efforts, and management efforts must address resilience and adaptation, including "no regrets" strategies like fire management of Lower Keys pine rocklands, management of invasive species, and restoration of wetland habitats. Eventually, however, the Florida Keys will become at least partly a marine habitat, a transition that must not be compromised by current management practices.

8.2 POLICY RECOMMENDATIONS FOR THE FLORIDA KEYS

8.2.1 WHAT THE SELECTED REPORTS DIDN'T REVEAL

The three reports featured in the previous section provide different perspectives, all highly relevant. The recommendations derived from the Coral Triangle study provide essential general and specific policy directions adapted to the Keys situation. The US Global Change Research Program report is a reminder that there is work to be done to improve the scientific knowledge to reduce the uncertainties surrounding the projected impacts, and convey a more convincing public message. Finally, Chris Bergh's work serves as a stark reminder of the worst risk facing the Florida Keys, sea-level rise, but in a very positive sense it also highlights the importance of managing and planning for resilience. We have secured great insights, relevant to the Keys, into:

- General and specific policy recommendations for local, statewide, and national adoption
- Recommendations aimed at reducing the uncertainty of climate science models by improving the research, as a condition for greater and more convincing advocacy
- Highlighting the worst climate change problem facing the Florida Keys, sea-level rise, while stressing the importance of encouraging resilience of natural and human systems.

None of the three reports deals with the influence of technological change, identified as a key driver of future scenarios by the IPCC and therefore a natural focus in this study. Figure 7.1 (Section 7.1.1) identifies the drivers of greenhouse gas emissions as population, economy, energy and technology, and land use. Energy and technology go hand in hand. Hoegh-Guldberg (2010d) presents a comprehensive picture of technology in relation to climate change, dealing with its main dimensions of physical technologies (based on fossil-based sources, renewables, and nuclear power), energy efficiency measures, and "green" and "blue" carbon approaches to improve and add to carbon sinks.

Another dimension, for a long time quite unrecognized, is the influence of economic theory on government policy (Hoegh-Guldberg 2010c). The prime recent example is how economics became dominated by the neoclassical school that (crudely expressed) taught that the market was right and should be allowed as much freedom as possible. There is a direct link between this school of thought and the circumstances leading to the current economic crisis. Furthermore, climate change economics emerged too late to become mainstream. Coming from other ways of thinking, the three reports we canvassed for policy advice contain no reference to the influence of economic theory on macroeconomic and financial policy.

Applying scenario planning, long advocated by the IPCC and a requirement in the current study, ensures that all relevant socio-cultural, technological, economic, environmental and political variables are taken into account in describing possible futures. Technological and economic change are explicitly included.

8.2.2 What the scenarios do tell us

The scenarios outlined in Chapter 7 leave little doubt that a "business-as-usual" approach would be verging on the suicidal, and the global economically based scenario A1 is too close for comfort to "business-as-usual". The only way forward is for the world to mobilize itself as fast as possible to expand to renewable technology, major energy efficiency measures, and the spread of green land-based technological change involving all nations, rich and poor.

The survival of the Florida Keys, with minimal damage from sea-level change and a reasonable hope to maintain some coral cover, depends on the comprehensive global adoption of environmental policies and rapid reduction of greenhouse-gas emissions. The adapted recommendations from the Coral Triangle study in Section 8.1.1 stress the need to tackle these issues globally, through effective and binding international agreements to reduce emissions. Local action is important in the interest of generating resilience, but the global commitment to reduce emissions is a precondition for success.

8.2.3 Key factors

This last section contains a proposed synthesis, starting with the summary of the adjusted Coral Triangle recommendations in Section 8.2.1:

- *Internationally*, it is urgent to achieve binding international agreement on emissions cuts, supported by national and regional targets in all countries.
- *Locally* (supported at state and national level), integrated coastal and marine management is essential, including funding for the Keys as an area at particular risk, holistic planning and building socio-ecological resilience. It should be underpinned by education and outreach to develop a prepared and informed community to better mitigate and adapt to climate change.
- *At all levels from local to national*, adapt existing conservation and development efforts for climate change robustness, and plan for adaptation efforts to play a role in economic stimulus and achieve "climate-smart" development.

The following list is presented as a possible synthesis further inspired by the specific findings of this research. It progresses from global to local perspectives:

1. There is overwhelming scientific consensus that climate change has become the most critically urgent issue of our time. There is a pressing need for effective international climate change mitigation now to limit the need to have to adapt in future.
2. Non-linear positive feedback responses in the climate system will become more frequent; intensified controlling action is urgently required. This is behind the targets to reduce greenhouse gas emissions by at least 80% by 2050, to stay below a 2^{O}C global temperature rise and 350 ppm CO_2. It is not just a matter for international negotiators; constant local, state and national action is required to reinforce and re-educate.
3. It is essential, therefore, to work toward an effective and binding international agreement on emissions control, with the onus on the developed world. Define substantial points for negotiation in time for the climate change conference in Mexico in December 2010 (COP-16) and achieve binding agreement for an effective successor to the Kyoto Protocol at the very latest at COP-17 in South Africa, in December 2011.
4. An environmentally friendly global scenario exemplified by the updated version of IPCC's "B1" is vital for long-term survival, backed by a prevailing spirit of strong community involvement. Continued encouragement of environmentally sensitive policies encompassing all nations is a primary objective, whatever it takes.
5. The political process in many leading countries has temporarily lost its sense of urgency and needs a wake-up call. The United States, as world leader, needs to ensure the passage of effective climate legislation through the Senate in 2010, but political reality suggests 2011. It must happen then.

6. It is high priority to promote and fund more research into new technologies including not only renewables but also energy efficiency and the protection of rural and coastal carbon sinks, plus the international diffusion of all renewable technologies, big and small, to the developing world. Diffusion is important to get the whole planet involved.
7. The Florida Keys are the most threatened area in the most threatened mainland State in the nation. They would not survive in a “business-as-usual” scenario. This gives the Keys as a mainstream American community a unique voice in the advocacy.
8. The existing strength of the integrated coastal management philosophy forms a solid foundation for Keys-based action. The keyword is resilience.
9. Local government is an important part of the solution, setting local targets, coordinating local initiatives, pushing state and national action from “below”, and generally helping to secure that the effort to build up resilience remains “climate-smart”.
10. The Keys economy must remain viable if the community has any chance of thriving. Sixty percent of the economic activity comes from tourism, with no real substitutes in sight. Tourist activity has been shifting from nature-based activities to historical tourism based on Key West. It is important to eliminate any dissonance between communities and induce maximum cooperation in their mutual interest.
11. Although mainly applied to the marine ecosystem centered on the coral reef, resilience is also a survival factor for other parts of the Florida Keys “super-ecosystem” – relating to natural areas, native species populations, and human communities.
12. Structural change threatens the resilience of the human community in the Keys, with an influx of occasional visitors owning local property but having no other local interest. It is important for survival to retain the strong current sense of community that remains. One way is keeping the young on side through education and outreach, encouraging them to stay, and to enlist their help working with and educating the older generation.

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