CLIMATE CHANGE AND THE FLORIDA KEYS

EXECUTIVE SUMMARY

FLORIDA KEYS NATIONAL MARINE SANCTUARY / NATIONAL ATMOSPHERIC AND OCEANIC ADMINISTRATION SOCIOECONOMIC RESEARCH AND MONITORING PROGRAM

FUNDED BY NOAA'S CORAL REEF CONSERVATION PROGRAM

The views and recommendations are the author's and are not necessarily endorsed by NOAA.

CONTENTS

OUTLINE

The executive summary reviews the origin of the Florida Keys climate change project and then describes the technique of scenario planning, followed by a description of the four main global scenarios of the Intergovernmental Panel on Climate Change in their original form, and how and why they were updated for this project.

These global sections are essential for understanding the Florida Keys projections, which are developed under four headings: a short general description and review of main strengths and vulnerabilities; how the local indicators of climate change were linked to the global indicators; presentation of the local scenarios in narrative and graphic form; and policy recommendations.

ORIGIN OF FLORIDA KEYS CLIMATE CHANGE PROJECT

The project was modeled on a study of the Australian Great Barrier Reef published in 2004, by leading coral reef biologist Professor Ove Hoegh-Guldberg and the writer.[1] A scoping study in 2005 established the feasibility of carrying out a two-year socioeconomic study of the Florida Keys and the surrounding reefs. The project was funded for the fiscal years 2007-08 and 2008-09, and was substantially completed in July 2010.[2]

Like the Australian study preceding it, the project was designed around the scenarios developed by the Intergovernmental Panel for Climate Change for its *Third Assessment Report* in 2001.[3] The Florida Keys research proceeded at a time when scientists were reaching a virtual consensus that dealing with global climate change had become more urgent since the original IPCC scenarios were written. This is demonstrated in four papers written as background for the main Florida Keys report:

1 *Changing global scenarios* as the threat of climate change worsens

2 *Limits to economic growth* as global warming makes the world more difficult to live in

3 *The changing economic paradigm* on the failure of economics to provide the best policy advice in a complex new world facing climate change and financial crisis

4 *Technology and climate change* on how best to alleviate global change through renewable and nuclear energy, more efficient energy use, and preserving carbon sinks to absorb atmospheric carbon dioxide. The ability to diffuse existing technologies to the entire world, and encourage genuine innovation in nations across the world, is also regarded as essential in the fight against climate change.[4]

THE ART OF SCENARIO PLANNING

Scenario planning has its origin in military war games during World War II. It entered the civilian world through the RAND Corporation and the Hudson Institute, founded by the cold-war strategist Herman Kahn who included “unthinkable” nuclear war in his thinking in order to study the strategic options that might be available. Although Kahn has been called the father of scenario planning, the technique has changed greatly in the past forty years, as the focus has moved away from planning how to live with the consequences of supposedly

inevitable conflict, to setting the boundaries for plausible possible futures. These deliberately exclude disaster scenarios which would shatter the planning effort anyhow.

Scenario planning became a major commercial instrument in the late 1960s, when a new framework was developed. One notable example, one of six scenarios written well before the oil crisis of 1973, was Shell's exploration of how the oil-producing countries would use their cartel power to put an embargo on any increase in output, precipitating a steep price rise. While other oil majors continued their practice of increasing refinery capacity by six percent year after year, as they had done almost automatically for two decades or more, Shell's scenario planning insights enabled the company to make quick decisions about its future refinery capacity. This gave it a strategic advantage in the 1970s as global demand for crude oil in fact stopped growing from 1974 and its competitors were slow to react.[5]

Shell and others developed the current main scenario planning model as it became increasingly difficult to predict sociocultural, technological, economic, environmental, and political change – complex elements that are all included in the *storylines* that are the core of the scenarios. The oil crisis is a prime example of largely unpredictable abrupt change with long-lasting effects, but so are the societal upheavals in the late 1960s caused by a growing sense of inequality and social injustice within individual countries and between rich and poor nations. The world has become a more turbulent place ever since the end of the seemingly predictable (western) world of the 1950s and the mid 1960s when the priority was largely on steady economic growth. Climate change then was not an issue and the capability of the planet to cope only began to be seriously challenged from the 1970s.

Scenario planning differs fundamentally from the prevailing practice of forecasting based largely on past trends – a procedure that became untenable as the future became essentially unpredictable beyond a short time span. In essence, scenario planners first develop a range of different storylines, designed to set the boundaries of what could be plausibly assumed to happen (short of collapse). Only then are the numerical and statistical projections worked out for each of the scenario futures, as a basis for planning for the best and avoiding the worst, and generally to expand the mental map of what might possibly happen.

Since the future is unpredictable, logically all plausible scenarios are equally likely to occur. In principle, having the global economy proceed at full speed, often called "business-as-usual", is no more likely to persist in a world bound to be full of unexpected events than an emerging environmentally conscious world where renewable energy and other sustainable technologies take over. Neither is there any guarantee against the current globalized economy fragmenting into larger or smaller regions for a variety of possible reasons.

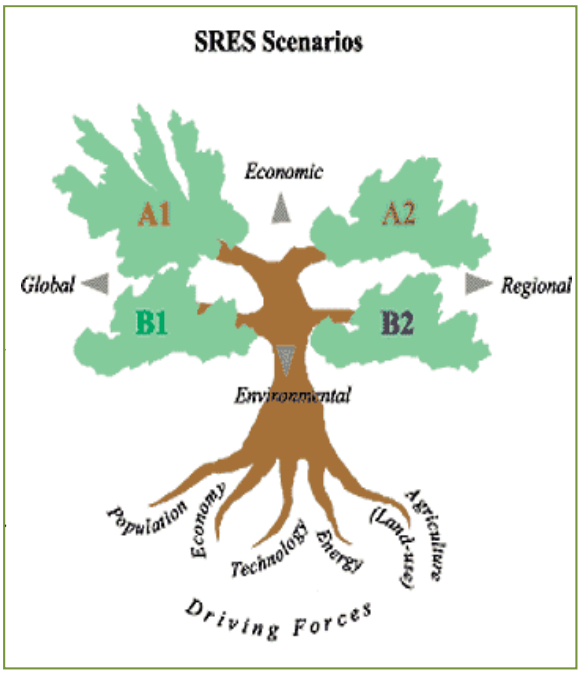
To sum up, a principal purpose of scenario planning is to set a *framework* of credible possible futures within which to plan for the best and avoid the worst case. No scenario is expected to happen in detail, but the framework sets the parameters for the planning.

THE GLOBAL IPCC SCENARIOS

The current set of IPCC scenarios were developed in the late 1990s for the IPCC's *Third Assessment Report* in 2001. They represent a significant improvement on previous IPCC scenarios published in 1990 and 1992, being based on proper storylines defined as equally

likely to occur and then used to develop multiple baseline projections derived from the stories. Another important change was that none of the emissions scenarios developed for the *Third Assessment Report* assumed that intervention would occur in the form of additional climate policy initiatives (including compliance with the Kyoto Protocol).[6] Each scenario was allowed to run to its "bitter end" at the end of the 21st century to show the full consequences of taking no direct climate action.

This is true scenario planning in the tradition set by Shell and others forty years ago, but on a time scale beyond the horizons of most commercial initiatives.



The IPCC's scenarios resulted from the combination of two main criteria, illustrated by a tree with four main branches portraying a vertical axis between economic development and environmental concern ("A" and "B"), and a horizontal axis from global to regional ("1" and "2"). So "A1" is a growth-oriented globalized scenario, "B1" the environmentally more friendly global equivalent, "A2" the regionalized or fragmented growth-driven variety, and "B2" the environmentally benign regionalized equivalent which has been given additional nicknames such as "regional equity" and "local solutions".[7]

The tree diagram has been criticized for being too simplistic to do justice to the diverse aspects contained in the scenario storylines, but it does provide a good overview of the four "marker" scenarios and the driving forces shown at the roots of the tree: population, the economy, technology including energy, and forestry and agricultural land use. But the critique is valid in so far as there is a tendency to ignore the subtleties of the storylines. Many users of the IPCC scenarios go straight to the numerical projections without proper reference to the storyline behind these projections.

This has become more important as the original scenarios have aged. The Florida Keys study updates the scenarios to get closer to an assessment of how the impact of climate change has become aggravated compared with the situation when the scenarios were first written.[8]

SUMMARY OF ORIGINAL SCENARIOS

The descriptions below are quoted from the *Special Report on Emissions Scenarios* (SRES), the source of the scenario analysis in the *Third Assessment Report*. The full scenario stories are shown in Chapter 7 of the Florida Keys report, which also describes how the global scenario might have been written in 2010; the impact of possible constraints on economic growth as the planet warms; and how the current situation may merge plausibly into the scenario storyline in the course of two decades or so. This provided the basis for the local Florida Keys scenarios and policy recommendations – the ultimate purpose of the project.

The SRES report noted that each storyline assumes a distinctly different direction for future developments, causing the four storylines to differ in increasingly irreversible ways. Together they describe highly divergent futures (as good scenario sets must if they are to delineate a plausible framework for planning) in terms of key characteristics such as demographic, economic and technological change.

For this reason, their plausibility or feasibility should not be considered solely on the basis of an extrapolation of current economic, technological, and social trends, says the SRES report. The stories in other words represent a major break with traditional forecasting techniques:

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). [The third variant is the main "marker" A1 scenario.]
- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but [like the other scenarios] without additional climate initiatives.
- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

UPDATED GLOBAL SCENARIOS

This section reviews how the scenarios might be amended today. First and foremost, the scientific assessment of climate change – shared by leading climate change economists like Nicholas Stern[9] – has become progressively more pessimistic over the past decade, reaching a position where global average warming above $2^{O}C$ is considered unduly risky, and

therefore atmospheric CO_2 should be reduced from present levels to 350 ppm or less, far below the assumptions made previously.[10]

What was considered worst cases in 2000 have moved closer to mainstream. The "limits to growth" model developed in Background Paper 2 suggests that there is some risk that the global warming generated even in the marker A1 scenario ("balanced" renewable and fossil fuel energy technology) might cause economic growth to turn negative towards the end of the century, or in the early 22nd century. In the fossil-intensive A1 version, even the most likely case indicates global economic decline during the second half of the 21st century.

The project report contains tables for each global scenario updated to take note of the matters raised in the background papers, especially the increased risk of rapid temperature rise and consequent constraints on global economic growth relative to the original IPCC projections. Each scenario table shows IPCC's unadjusted global economic product projections alongside currently estimated "most likely" and "worst case" projections. Given that worst cases have tended to move towards the center of the probability distribution[11] the projection offered in the report lies halfway between the "most likely" and "worst" case.

A1: EXPECTED TO RUN INTO BARRIERS

The assumption in the scenario story that incomes in all countries will converge looks as optimistic in 2010 as when it was first made. Some convergence may be happening but there is a very long way to go, including achieving more equitable income distributions within countries. Secondly, an updated A1 scenario would give more space to Asian values, rather than the Euro- and US-centric view of the original A1 scenario.

Thirdly, the scenario story envisages a change from "conservation" to active "management" of natural and environmental services. Good management is the obvious key in any well-run ecosystem, but conservation remains a clear management guide. Envisaging a change *from* one *to* the other does not make a lot of sense even in a singularly growth-driven scenario which, if successful, would want to generate a strong tourist industry. The emphasis today is on ecological resilience, backed by a growing understanding of how ecosystems are interconnected and how positive feedback effects develop through tipping points in the climate models. A major conservation element in the management model is required to encourage strong tourism, not least in marine sanctuaries.

The unadjusted projection in the SRES report for all three A1 variants is over $500 trillion in 1990 prices (similarly priced, the world product for 2010 is about $38 trillion). These projections assume that global economic growth will proceed without disturbance despite temperature increases of $3^{O}C$ or more; $5^{O}C$ or more in the fossil-intensive version of A1. Many economists and scientists have declared that relentless pursuit of "business-as-usual" could lead to disaster, but without offering quantitative estimates.[12]

The project report contains the estimate (with the appropriate reservations when offering a simple pioneering model) that the main projection of the A1 marker scenario will reach $324 trillion by 2100, 39% below the unadjusted IPCC projection. Annual growth will be reduced between 2075 and 2100 to only 0.5%, which does not augur well if the scenario were to continue without mitigation into the 22nd century.

For the fossil-intensive variant, A1FI, the main projection is for the world economic product to peak in 2075 and then start to decline towards half the unadjusted level by 2100. Even in a short recession often defined as two or more quarters with declining GDP, negative economic growth causes great anxiety. How the reaction would be to protracted decline is almost unimaginable, especially in the economy-driven A1 scenario world.

The environmentally most benign A1 case, assuming transition to renewable energy technology, naturally provides the best results of the three variants, reaching a level 27% below the unadjusted IPCC projection for 2100. In the worst case, however, even it turns to negative growth in the final decade of the century.

B1: STANDING UP BEST

The caveat here is that the greenhouse gas levels projected by the IPCC are much higher than is becoming acceptable if the average world temperature is to stay within $+2^{O}C$ of pre-industrial levels. What should be added to the story when told today is the need to reduce atmospheric CO_2 to below 350 ppm using all possible acceptable technologies: a rapid switch to renewables, a role for nuclear technologies, increased emphasis on energy efficiencies, a higher profile for agricultural land use and forest management, the protection of oceanic sinks, and the need to involve the entire world including the least developed countries. It is encouraging that genuine innovative activities are beginning to happen in more nations, but it is also essential to keep diffusing appropriate technologies to all countries including the poorest fifty, two-thirds of which are in Sub-Saharan Africa.[13]

B1 is the only scenario showing continuing growth in the worst case when constraints are put into the model to reflect the impact of warming on economic growth. All other worst-case scenarios point to economic decline in the second half of the 21st century. The original growth rate was much lower than for the A1 scenario family, reaching $328 trillion in 2100 compared with $38 trillion currently (1990 prices). But it is more sustainable. The "most likely" IPCC case is only 3% below the unadjusted IPCC projection, while projecting midway between the "most likely" and "worst" case reduces the level in 2100 to $295 trillion, a fairly modest 10% below the unadjusted projection.

Significantly, this level is only 9% below the $324 trillion projected for the A1 marker scenario, and with better sustained GDP growth in the B1 version.

A2: NEEDS DOWNGRADING COMPARED WITH THE ORIGINAL

The idea that the world economy might split into a number of distinct regions is not hard to imagine; even though the current observed trend is towards globalization the trend is by no means unchallenged. There are regions today that could conceivably become isolated and follow their own different social, cultural and economic paths isolated from the global economic community.

Scenario A2 is exposed, and burdened with unsustainable population growth, projected in the SRES report to grow to 15 billion people by the end of the century (fertility rates have declined since the scenario was written, but even 12 or 13 billion would be clearly unsustainable). Some of the other basic assumptions should be re-examined, including a review of escalating conflict associated with local warfare and international terrorism in an

A2 setting. Written in 2010, this scenario would rival the fossil-intensive A1 scenario as the worst case associated with climate change, with the added disadvantage that it would be harder for the poorer and more fragmented A2 world to take adaptive action to avoid the worst effects.

The risk of armed conflict as the population multiplies, regions develop at different rates, and food sources struggle to keep up, suggests that the global economy may start going backwards even earlier than this model suggests. The projected world product of $105 trillion is a mere 43% of the unadjusted IPCC projection of $243 trillion in 2100, and the worst case is economic collapse in the second half of the 21st century to only $41 trillion, 17% of the unadjusted IPCC projection. Clearly A2 is a scenario to avoid if at all possible, even more so than according to the SRES report in 2000.

B2: UNDERVALUED IN THE ORIGINAL

The defining feature is environmental awareness, encouraged in strong, well-educated and cohesive communities putting high priority on equality, health, and environmental protection. The regional structure is big enough to allow for successful policies on equality, health and the environment, and there is sufficient communication across the globe to allow regions to cooperate on environmental protection. These features were undervalued in the IPCC report, which criticized the scenario for an alleged failure to develop conventional technology, limiting economic growth with falling R&D expenditure and constraints on the international diffusion of technology and knowhow.

The role of technology in a B2 scenario written today would probably be viewed more positively than in the original, which seems to have largely ignored the value of locally committed community groups in addition to underestimating the potential to increase the world's carbon sinks through better agricultural and forestry practices. Technological diffusion rates have also increased greatly since B2 was written, thus involving more and more countries, and there are strong signs that real innovation (as distinct from diffusion of existing technologies) is spreading beyond a few rich nations to China, India, Brazil and many other countries.

The unadjusted IPCC world economic projection for B2 was marginally lower than for A2, which must now be considered the most disastrous scenario, ($235 trillion compared with $243 trillion in 2100). This is unduly low. It is assumed that a new base projection midway between B1 and B2 be substituted ($282 trillion at the end of the century). The result is a new "most likely" and "worst" case for B2 and a new projection for 2100 of $234 trillion, 28% below the amended unadjusted projection.

In the Florida Keys context, B2 with its explicit emphasis on local solutions and local communities would add a valuable facet to the globally oriented environmentally friendly B1 scenario story.

THE FLORIDA KEYS

The summary description is in three parts: Monroe County/Florida Keys with an emphasis on its dependence on tourism; threats; and strengths. We can then link the global indicators to

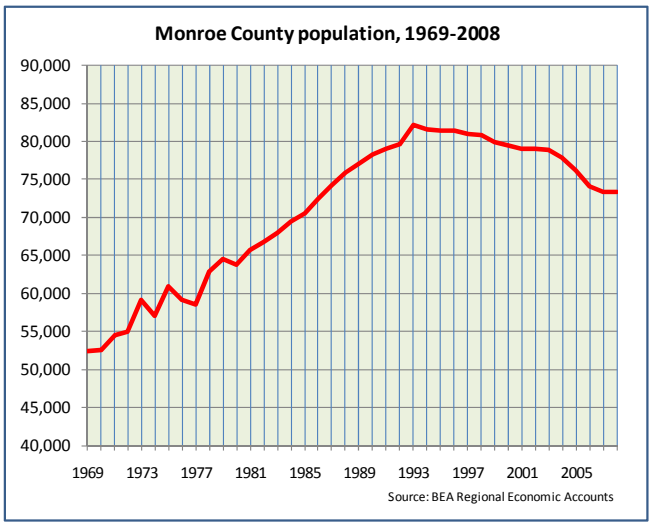
the available local equivalents in the subsequent section, setting the stage for presenting the four scenarios as they apply in the Keys, and listing the policy recommendations in the concluding section.

MONROE COUNTY AND THE IMPORTANCE OF TOURISM

The main concern is with the populated part of Monroe County that comprises the Florida Keys from Key West 107 miles (172 km) northeast to Key Largo. The Upper Keys include Key Largo, Tavernier, and Islamorada. Marathon is the main population center in the Middle Keys. The Lower Keys, from the southern end of the Seven Mile Bridge south of Marathon, have two quite distinct parts, a collection of relatively big islands of which the largest is Big Pine Key, and the historical center of Key West, which adds an important dimension.

The Keys lie between the Gulf of Mexico and the Atlantic Ocean – dangling from the mainland like "hurricane bait" as the Monroe County Local Mitigation Strategy Plan of 2005 expressed it. Hurricane activity is naturally a prime concern. The capacity of the only main thoroughfare, the part of US 1 known locally as the Overseas Highway, is a important issue, though evacuation also depends on the capacity of mainland highways to help escape hurricane zones.

The Keys are of very low elevation with the main islands mainly between four and seven feet above the current sea level (1-2 m). This is a main factor in the analysis of climate change.



The population of Monroe County has been falling for almost two decades, after growing from 52,500 in 1969 to 82,200 in 1993. The latest count at the time of writing was 73,300 in 2008. In the local scenarios, the initial population for 2010 is set at 72,000. Though this may prove to be slightly on the low side it makes little difference to the local Keys scenarios shown towards the end of the executive summary.

The economic activity in Monroe County is dominated by tourism, accounting for about 60% of the total "County product". Commercial fisheries are a distant second, though they remain economically and socially significant. There is little industrial and agricultural activity adding to the total economic product through sales outside the County.

The high tourism component is based on two distinct features: the marine environment (supplemented by land-based natural attractions) and Key West. The environment includes the unique marine habitats in the FKNMS and other sanctuaries, and land-based parks providing protection for threatened fauna like the key deer on Big Pine and No Name Keys, and flora including the botanically diverse pine rocklands in the Lower Keys and tropical hammocks throughout the Keys. In an important sense, the Keys form a "super-ecosystem" of interdependent components relating to its natural areas, native species populations, and

human communities. At the southernmost point of the continental United States, Key West is in a class of its own as a historic center.

The essential facts on tourism trends come from two visitor surveys conducted by NOAA in 1995-96 and 2007-08.[14]

- There has been a decline 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 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. The average age of tourists increased from 46.1 to 49.3 years, the proportion of males fell from 73% to 64%, and there was a significant increase in median household income, estimated at $78,000 in 1995-96 and $102,000 in 2007-08 (constant 2008 prices).
- As well as day travelers visiting only one district (a growing proportion being cruise ship passengers visiting Key West), overnight visitors (the great majority arriving by car) were also less mobile in 2007-08 than in 1995-96. This appears to be 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. It all favors Key West over Key Largo and other districts. With less incentive to engage in sea-based activities, 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 noticeably less satisfied with the state of coral reef health.

THREATS

In 2008, a series of workshops were conducted with a broad range of community leaders to help establish key issues for the future of the Keys. The results provided an important supplement to the factual information which is available through official statistics, surveys, scientific papers, and other records. The primary finding in every workshop was that the overriding issue is *climate change*.

The main manifestations of climate change in the Florida Keys, *rising sea temperature, sea-level change, ocean acidification, and increased hurricane activity*, are crucial threats. Many or most other identified vulnerabilities are or will be aggravated by these factors, including water supply, pollution from outside the Keys, and influences on reef health, sustainability and fisheries.

The limited *carrying capacity* of the Florida Keys may not yet be directly associated with climate change, but with the rising specter of sea-level change this is projected to change radically even on the most optimistic assumptions. This is based on an analysis by TNC's Florida Keys program director, Chris Bergh, which was a vital information source for this project.[15]

Carrying capacity (in the absence of projected sea-level change) has long been a matter for concern and the issue has been actively addressed by the Board of County Commissioners and County officials. The Rate of Growth Ordinance (ROGO) was introduced in 1992 to limit the number of building permits, and restrict building heights. The aim at the time was to bring the population in line with the mandatory time for hurricane evacuation (obviously no longer the sole consideration). The chart on page 8 shows the population peaking in 1993 and since falling by an estimated 10,000, though not solely due to ROGO.

Carrying capacity was also the subject of a study undertaken in 2002, based on an endangered species model including hammocks connectivity and threatened wildlife mainly in the Lower Keys. It was criticized for failing to acknowledge changes in the demographic and socioeconomic structure in the Florida Keys, the socioeconomic impact of tourism, and the character of the surrounding marine ecosystem.[16] In any case, the study has been in existence for almost a decade, and the climate change outlook has become much more severe. Reappraising future carrying capacity should be an urgent priority.

Water supply is another concern that limits the capacity of the Keys. The Florida Keys Aqueduct Authority (FKAA) channels water from a well field near Florida City in Miami-Dade County. From a 1937 start it was stepped up in 1939, when the US Naval Air Station near Key West was re-activated and a military build-up started. 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 is supplemented by the deep brackish-water Floridian Aquifer (lime-softened at the Florida City water treatment plant), and by desalination plants at Stock Island and Marathon used in emergencies only.

FKAA faces significant challenges in meeting the projected water demand for the next twenty years, especially since The Biscayne Aquifer is under increasing strain because it also serves as the principal source of fresh drinking water supply for the South Florida Metropolitan Area (Miami-Dade, Broward and Palm Beach Counties). There are also growing concerns that sea-level rise will cause saltwater intrusion into the freshwater aquifer.

Pollution from outside the Keys area is associated with living immediately south of a 5.5 million population center, which requires careful management of ocean outfalls and close cooperation between authorities in South Florida. It is also intimately associated with the degraded Everglades polluting Florida Bay between the mainland and the Upper Keys. Pollution from the Mississippi and other mainland US rivers affects water quality in the Gulf threatening neighboring land areas. Finally, the Deepwater Horizon disaster on the Louisiana was sufficiently close to the Keys to revive the potential threat associated with offshore deep sea oil exploration, though the damage to the Keys appeared to be minor.

Coral cover, a proxy for general reef health, was almost halved between 1996 (12.3%) and 2008 (6.4%) in the Sanctuary area.[17] This extended a general trend over many decades showing the coral cover in the Caribbean generally being decimated.

In parallel to this, *commercial fisheries* landings in Monroe County were halved between 1986-88 and 2007-09. Of these, landings of groupers and snappers and other reef fish declined by 37% and spiny lobsters (with Monroe County representing almost 90% of the total for Florida) by 39%. Landings of pink shrimp, previously a very important part of the total catch, declined by 82%.[18]

Monroe County accounted for an average of 13.2% of total Florida fisheries landings between 1986 and 2009. Its share of the State total remained close to 13% in 2009, confirming its importance over a long period. Total commercial fisheries in Florida declined by 54% using the same three-year average measure as for Monroe County.

The *population structure* is changing. One of the main themes in the scenario-planning workshops in 2008 was population change. It is becoming less affordable to live in the Keys with rising property values, which cause local residents to sell out at high prices, especially for waterfront property. People moving in are often buying for investment to resell, or are very wealthy Americans or Europeans perhaps buying their third or fourth homes.

The surveys summarized on page 9 identified an increasing number of visitors owning or leasing their own condominiums or time-share facilities, and therefore lost to local citizens as the carrying capacity gets stretched to the limit.

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 because of lack of opportunities. 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.

STRENGTHS

The style of sanctuary and other natural resource *management* is a key strength. “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 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 a major strength.

The key issue facing sanctuary management in conditions of threatening climate change is to enhance 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.

Monroe County also benefits generally from a progressive team well aware, among the Board of County Commissioners and the administrators, of the risks facing the Keys. Climate change is a main concern, naturally focused on the threat of sea-level rise.

Building up resilience to improve reef health is, as just noted, a key concern of the FKNMS. It is the dominant theme in all ongoing work, strongly associated with The Nature Conservancy whose Key Largo conference on the topic in 2008 represented a milestone. It demonstrated the commitment of scientists from universities and the Sanctuary itself, and highlighted the ongoing collaboration between the FKNMS and the Great Barrier Reef Marine Park Authority which has taken place to the mutual benefit of both organizations.

In June 2010, a five-year marine action plan for South Florida was launched under the Florida Reef Resilience Program (FRRP) as a direct result of the Key Largo conference in 2008.[19] It was welcomed in a foreword by the regional director of NOAA's Office of National Marine Sanctuaries, Billy Causey. The action plan, he wrote, was the culmination of five years of collaborative effort among prominent scientists, managers and user groups, “grounded in the concept of "resilience", or ability of the ecosystem to bounce back from impacts” ... “given the inevitability of warmer, more acidic oceans, and rising sea levels.”

The ongoing research is itself another important strength, ranging from the collection of coral cover and fisheries data and Steven Miller’s and Mark Schiappone’s ongoing benthic program, to the work of the Florida Fish and Wildlife Research Institute scientists under John Hunt’s leadership, and contributions by scientists like James Bohnsack and Jerald Ault to which we must naturally add the late Brian Keller, Bill Precht, Scott Donahue, and others from within FKNMS ranks. In association with MOTE Laboratories, Martin Moe is carrying out valuable work on the ecologically essential herbivorous sea urchin *Diadema antillarum*, while Ken Nedimyer works to restore staghorn and elkhorn coral to the reef.

This work is matched in the socioeconomic area within NOAA itself, led by the Office of National Marine Sanctuaries chief economist, Bob Leeworthy, and elsewhere by others like David Loomis, Jessica Bennett, and Manoj Shivlani. Many others could be mentioned.

Finally, the Keys benefit from some highly committed local organizations including GLEE (Green Living and Energy Education) and 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. It also, as noted repeatedly, has an active and dedicated local office of The Nature Conservancy, which takes the practical leadership in the coral reef resilience program.

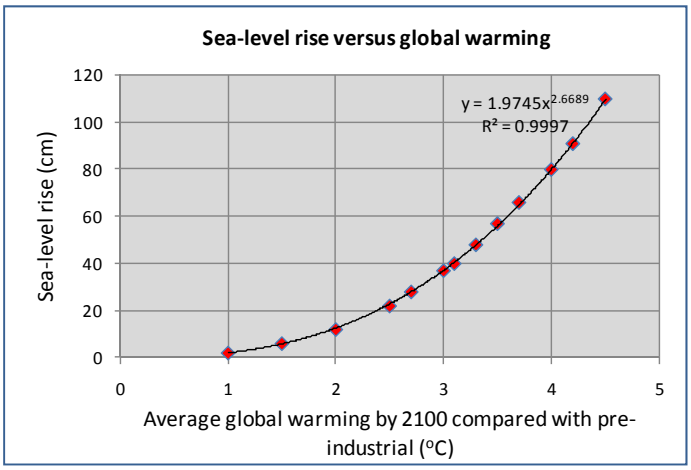
In summary, the strength of the area is the ability to work together to achieve better resilience and save the interconnected Florida Keys ecosystem and its human communities.

LINKING THE GLOBAL AND LOCAL SCENARIO STORIES

It is essential to base the analysis of a changing climate in a local area on global research, but also to link key numerical indicators together, as far as the data permit. At the global level, the numerical scenario projections are based on average global warming, sea-level rise, ocean acidification, and change in global economic product.

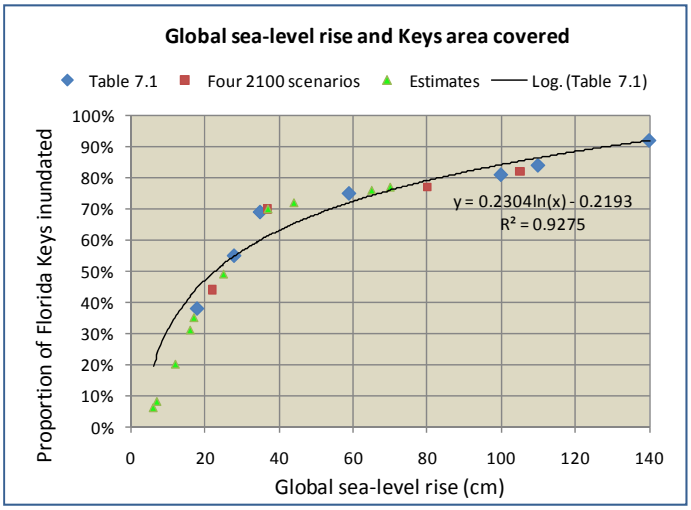
In the Keys, the variables considered were population, coral cover (proxy for marine-based tourism), area remaining after sea-level rise (determining population size assuming that carrying capacity is fully stretched), and the value of the area remaining after sea-level rise (a partial indicator of local income).

FORMAL LINKS BETWEEN GLOBAL AND LOCAL INDICATORS



The crucial link in the Florida Keys context that could be demonstrated was between average global warming and average global sea-level rise. The link is well described by a power curve as shown on the first of three charts demonstrating the linkages. It shows how the sea level is expected to rise as the temperature increases: 12 cm if the planet warms by 2°C, through 110 cm at 4.5°C warming – values that are generally in tune with recent literature.

The second relationship is based on the empirical research in Chris Bergh's 2009 report on the impact of sea-level rise in the Keys, which contains a table (page 25) showing the area at risk at different global sea-level rises. The calculation in the second chart is based on the blue diamond-shaped dots.[20] The best single relationship between the two variables is logarithmic, but the actual shape might be better approximated by two straight lines: one suggesting that 70% of the land will be lost as the global sea level rises up to 35 cm, another showing a much slower rise towards a 92% loss as the sea level increases to 140 cm, as one prominent scientist, Stefan Rahmstorf, has stated is entirely possible.

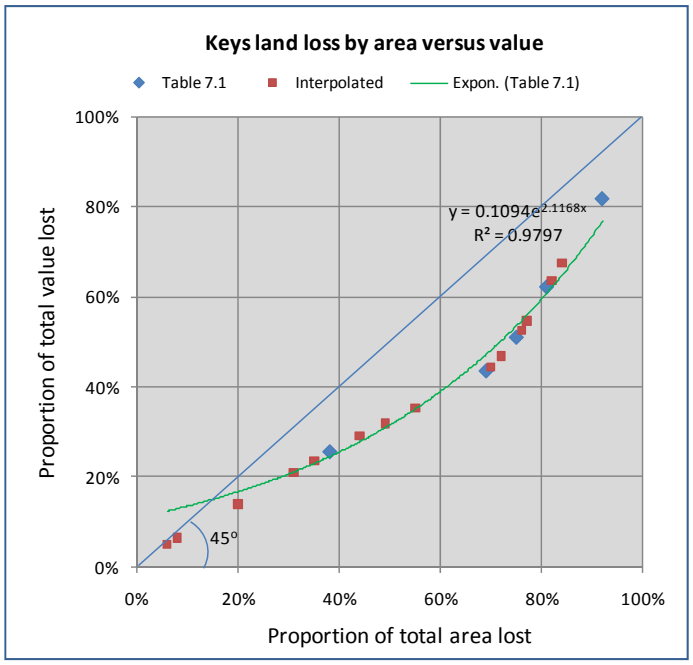


This combination of an initially rapid rate of land loss as the sea level rises has consequences for the scenario predictions, as shown below. The impact of sea-level rise in the growth-driven scenarios (A1 and A2) is much more rapid than for the environmentally better tuned scenarios, especially B1.

Bergh's analysis finally shows that the total value of the land decreases more slowly than the land area. The third chart shows, for instance, that when almost 38% of the area is lost (which is the most optimistic projection at an 18 cm global sea-level rise), the total value decreases by 26%. The maximum discrepancy is when the global sea level rises by 59 cm: 75% of the land is lost but "only" 51% of the land value.

It is implausible to assume, however, that the total income of the remaining residents in the Keys benefits fully from increased values of the remaining land. Much of the increased

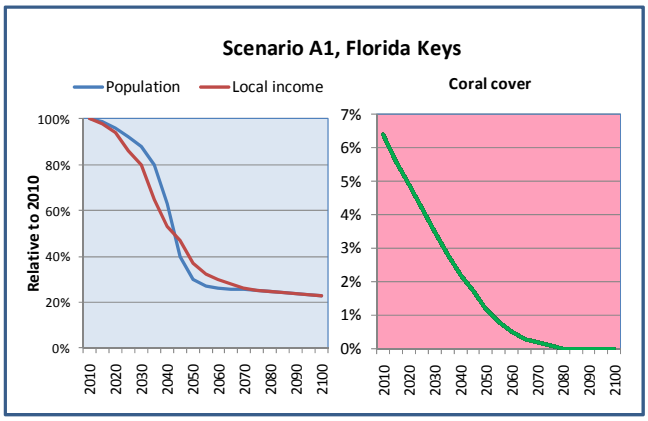
income will benefit non-residents. The report concludes, after a considerable amount of analysis, that the total income of Keys residents will be determined by two factors: the value of marine-based tourism approximated by the projected remaining coral cover, and the value of the remaining land in Key West and the rest of the Florida Keys. 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.



SCENARIOS FOR THE FLORIDA KEYS

A1: GROWTH AND GLOBALIZATION

The high global economic growth suggested by this scenario 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 into sea-level rise in the Keys is the dramatic land loss between 2035 and 2050 in the A1 scenario as the global temperature increases from 2°C to 3°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. At the *most likely* IPCC estimate of 28 cm global sea-level rise, 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. Without Chris Bergh's research into the connection between the topography of the Keys and the projected sea level, the population decline would have been expected to be much more gradual.

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 a proxy of future marine-based tourism potential. 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 showed total spending by cruise-ship passengers increasing strongly despite a fall in per capita spending based in Key West, and spending by overnight visitors also increased compared with 1995-96. These factors were important although the total increase between the two survey dates 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 some evidence that an acidified ocean may affect the ability of fish to navigate. 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. 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.

B1: A SUSTAINABLE WORLD

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

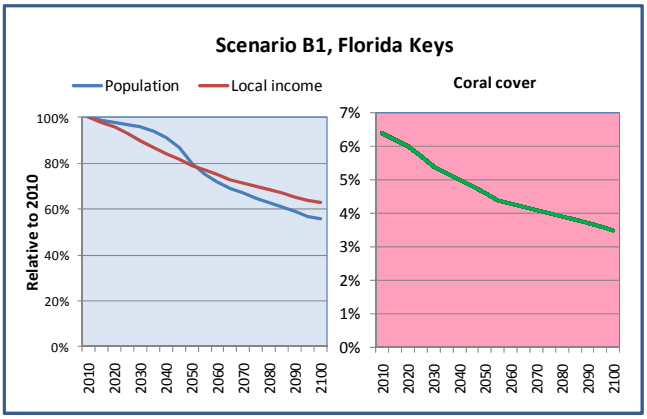
base this on renewable energy sources as is already happening on No Name Key). Young people also respond by more of them staying rather than abandoning the Keys; an issue that came up at the Key Largo scenario-planning workshop in 2008 at the initiative of two young women professionals. Another young woman participant in the same workshop called the Keys potentially "a living laboratory for climate change", which could help attract young people, or keep them from leaving.

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[21] 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.

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.

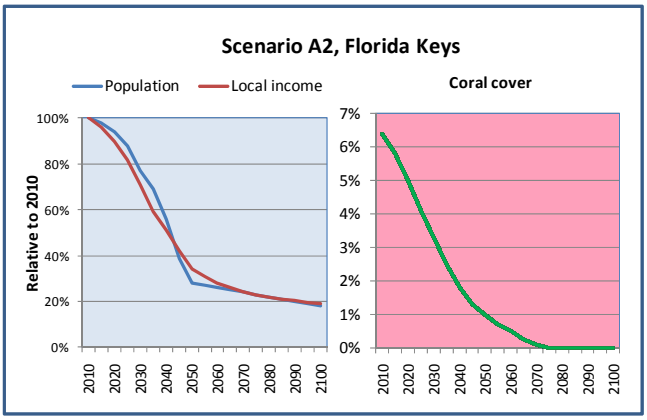
The relatively high projected coral cover (3.5% in 2100) is assumed to be consistent with the assumption on acidification, as well as being crucially dependent on the continued resilience policy of the FKNMS and other organizations, and the community's active involvement. Finally, the income estimates 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.[22] It is important, in any case, that Key West remains a crucial part of tourism, and there is good cooperation between the historical and nature-based part of the industry.



The graphic results for the main local variables contrast dramatically with the results shown for the growth-orientated A1B scenario.

A2: A FRAGMENTED WORLD ASPIRING TO GROWTH

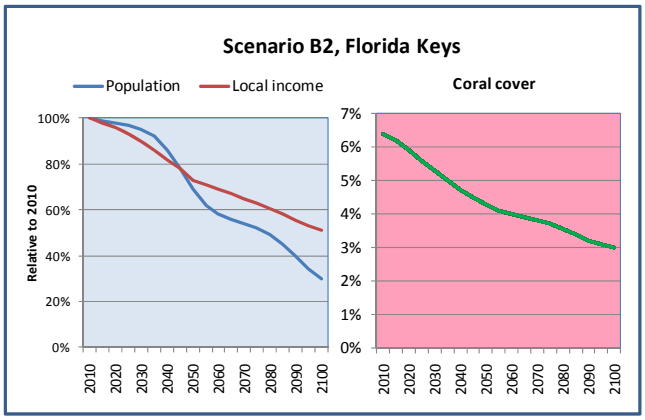
Some of what is written under A1 applies here as well. But the situation is worse under A2, which appears to be one to be most strenuously avoided. That goes for the world, for the United States, and for the Keys. One factor would be real estate values, which would be lower than in A1. Any environmentally 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,[23] 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. Any remaining coral cover will disappear by 2075. All four variables represent a case worse than the A1 scenario.

B2: AN ENVIRONMENTALLY SENSITIVE REGIONALIZED WORLD



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. 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.

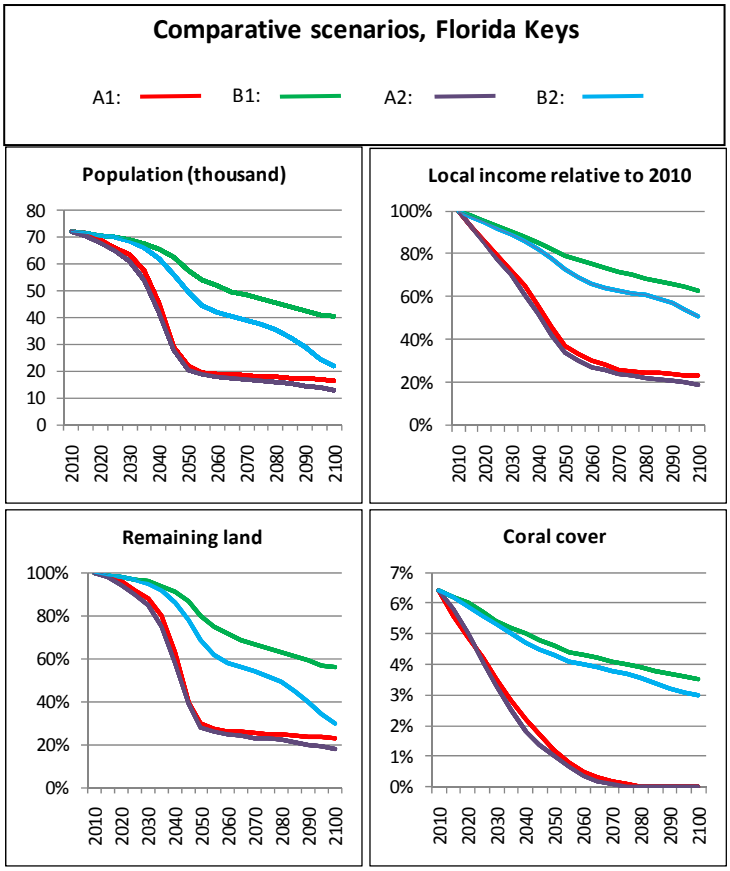
There will be a viable tourist industry based on Key West's historic attractions and the nature-based activities of the Keys, and local residents will dominate, rather than outsiders leasing or owning condominiums and time-share accommodation.

One observation in the graph looks surprising but it is based on TNC's empirical work on sea-level rise. It 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.

COMPARING THE LOCAL SCENARIOS

The final graph 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), local income relative to 2010, remaining land (which governs population numbers), 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 regional environmental scenario, B2, and the "balanced" renewable/fossil version of the global economic scenario, A1B.



POLICY RECOMMENDATIONS

A set of recommendations for the Coral Triangle in Southeast Asia was adjusted to the Keys as guidance for this project. This contribution is gratefully acknowledged.[24] In summary:

- *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 offered as a 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 atmospheric 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, across political differences.

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.

HHG November 15, 2010

ENDNOTES

[1] Hans and Ove Hoegh-Guldberg (2004), *The Implications of Climate Change for Australia's Great Barrier Reef.* WWF Australia and the Queensland Tourism Industry Council. http://www.wwf.org.au/publications/ClimateChangeGBR/.

[2] Hans Hoegh-Guldberg (2010), *Climate Change and the Florida Keys*.

[3] Nebojsa Nakicenovic and Rob Swart (ed.) (2000), *IPCC Special Report on Emissions Scenarios* (2000). http://www.grida.no/climate/ipcc/emission/.

[4] The four background papers are linked to the NOAA/FKNMS socioeconomic website following the main report.

[5] Kees van der Heijden (1996), *Scenarios: The art of strategic conversation*. John Wiley & Sons.

[6] Bastien Girod, Arnim Wiek, Harald Mieg and Mike Hulme (2009), 'The evolution of the IPCC's emissions scenarios'. *Environmental Science and Policy* Volume 12, No. 2, 103-118. April.

[7] Girod et al. (2009).

[8] Work is progressing within the IPCC to produce a new set of scenarios (with revised rules) for the *Fifth Assessment Report*, due in 2014 (Richard Moss et al. (2008), T*owards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies: IPCC expert meeting report*. 19-21September, 2007, Noordwijkerhout, The Netherlands). http://www.ipcc.ch/pdf/supporting-material/expert-meeting-report-scenarios.pdf. Meanwhile, the update in this report must suffice.

[9] Lord Stern is the main architect of the new climate change economics, following the publication of the *Stern Review on the Economics of Climate Change* in 2006. He has since written a shorter version (*A Blueprint for a Safer Planet: How to manage climate change and create a new era of progress and prosperity*). The Bodley Head, London, 2009).

[10] 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. See, for example, James Hansen et al. (2008), 'Target Atmospheric CO2: Where Should Humanity Aim?' *Open Atmospheric Science Journal*, Vol. 2, 217-231.

The call for "economics of 350" gathered impetus during 2009 culminating in the Copenhagen Accord in December which 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.

[11] Professor Ross Garnaut used that term in the major Australian climate change analysis in 2008 (*The Garnaut Climate Change Review: Final report*. September 30. http://www.garnautreview.org.au/. Canberra, ACT, Australia). Harvard Professor Martin Weitzman calls the phenomenon "the fat tail of the probability distribution", noting that previously quite unlikely catastrophic events have become less unlikely. This is consistent with the normal distribution bell curve becoming flatter, with less central tendency and "fatter tails" (M. L. Weitzman (2009), 'On modeling and interpreting the economics of catastrophic climate change.' *The Review of Economics and Statistics*, Vol. XCI, No. 1:1-19. February).

[12] James Lovelock tops it all with the ultimate version of a "no numbers all story". The final paragraph of *The Revenge of Gaia* (2006, p 159) begins: "Meanwhile in the hot arid world survivors gather for the new Arctic centers of civilization; I see them in the desert as the dawn breaks and the sun throws its piercing gaze across the horizon at the camp. … Their camel wakes, blinks and slowly rises on her haunches. The few remaining members of the tribe mount. She belches, and sets off on the long unbearably hot journey to the next oasis."

[13] The full description of the role of technology is in Background Paper 4, *Technology and Climate Change.*

[14] The surveys are posted on NOAA's socioeconomic "sanctuary science" web pages for the Florida Keys: http://sanctuaries.noaa.gov/science/socioeconomic/floridakeys/recreation/linking08.html.

[15] Chris Bergh (2009), *Initial Estimates of the Ecological and Economic Consequences of Sea-level Rise on the Florida Keys through the Year 2100.* The Nature Conservancy, Sugarloaf Key, FL. August. http://www.frrp.org/SLR.htm.

[16] URS Corporation (2002), *Florida Keys Carrying Capacity Study: Final report.* For the US Army Corps of Engineers and the Florida Department of Community Affairs. Criticized by National Research Council (2002), *A Review of the Florida Keys Carrying Capacity Study*. National Academy Press, Washington DC.

[17] The source of the data is the Coral Reef Evaluation and Monitoring Project (CREMP), part of the FKNMS Water Quality Protection Program and administered by the Florida Fish and Wildlife Research Institute (FWRI) under John Hunt. Other regular research into coral health is led by Steven Miller and Mark Chiappone based on randomly stratified benthic sampling to make it representative of the reef geography of the Keys. Since this program began in 1999 it has brought many new insights to bear.

[18] Source: FWRI.

[19] Florida Reef Resilience Program (2010), *Climate Action Plan for the Florida Reef System 2010-2015.* With a foreword by Billy D. Causey. June. http://frrp.org/SLR%20documents/FL%20Reef%20Action%20Plan-WEB.pdf

[20] The "Table 7.1" reference is to the main *Climate Change and the Florida Keys* report.

[21] As outlined by Bergh (2009).

[22] Bergh (2009, page 28).

[23] A doubling of Florida's population was estimated by Paul D. Zwick and Margaret H. Carr (2006), *Florida 2060: A population distribution scenario for the State of Florida.* (http://1000friendsofflorida.org/PUBS/2060/Florida-2060-Report-Final.pdf).

[24] While the recommendations are those of the author and do not represent official NOAA positions, they benefited from the recommendations of a study of the Coral Triangle in Southeast Asia (Ove Hoegh-Guldberg et al. (2009), *The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk.* WWF Australia). Co-authors included Lara Hansen (EcoAdapt) and the author. (http://assets.panda.org/downloads/climate_change___coral_triangle___full_report.pdf). Sincere acknowledgments are due to Lara and her Keys-based colleague Alessandra Score for adapting the published Coral Triangle recommendations to the Florida Keys.

The final recommendations were also inspired by Chris Bergh's report on sea-level change in the Keys (repeatedly quoted in this summary) and by the second report of the US Global Change Research Program (Thomas Karl et al. (ed.) (2009), *Global Climate Change Impacts in the United States: A state of knowledge report from the U.S. Global Change Research Program.* Cambridge University Press).