

## Testimony

Submitted by:

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Implementation of the Coral Reef Conservation Act of 2000 and the impact of climate change on coral reefs

Subcommittee on Fisheries Conservation, Wildlife and Oceans,

Committee on Resources

U.S. House of Representatives

### 1. Executive Summary

In his letter of invitation, Chairman Gilchrist requested information on five questions or topical areas. These questions, quoted below, are used as the organizing theme for the testimony. This Executive Summary section presents capsule overview responses to the points, each of which subsequently is addressed in more depth in an individual section of the testimony. Key points are underlined.

#### Requested topics of discussion:

- 1.1 ***“...how the interplay between climate, the marine environment, and coral ecosystems has changed, and the resultant and predicted effects.”***
  - 1.1.1 Humans have altered the carbon, nitrogen, phosphorus, water and sediment cycles in major ways, with effects at both local and global scales on systems that take hundreds to thousands of years to fully respond.
  - 1.1.1 Overexploitation of fisheries and the ecosystems that support them have added a direct and immediate impact to the changes set in motion by larger-scale geochemical modifications.
  - 1.1.2 Some of the results of these changes are understood and some predictions are possible, but the critical fact is that the combined changes have put the earth system on a trajectory for which there is no precedent or analog in evolutionary history, and from which we cannot turn back in any prompt or easy fashion.
- 1.2 ***“...whether the range of atmospheric and marine conditions and the extent and intensity of coral declines is expected to be from natural climatic cycles and variations or if these declines stem from human-driven factors.”***
  - 1.2.1 There is undoubtedly a component of reef stress and decline that is related to natural cycles and variability; however, we are unable to determine that with any precision because it is being overwhelmed and reinforced by human factors.

- 1.2.2 In areas where local and regional human environmental degradation and overexploitation are significant, these factors far outweigh any effects of natural variability.
- 1.2.3 Human-driven, global-scale changes in climate and in ocean chemistry are becoming the dominant stress factors in areas removed from direct human impacts, and are also contributing significantly to the combined stresses elsewhere, and will increase in importance in the future.

**1.3 “...of what importance compared to other factors are climate effects in coral reef declines.”**

- 1.3.1 Climate effects are almost certainly the dominant cause of massive, global-scale bleaching events, although vulnerability and mortality may be influenced by local factors in many locations.
- 1.3.2 Where reefs are close to, and exploited by, human populations, or where they are under stress from local or regional sources, climate factors will be a contributory but not necessarily primary factor in decline.
- 1.3.3 The relative importance of climate factors will continue to increase for decades, as present-day ‘commitments’ to additional CO<sub>2</sub> release and climate change play out in the earth system. Local-scale human impacts can be controlled and reversed in the short term; major climate and earth process changes cannot.

**1.4 “...what recommendations would you provide for stopping and reversing these declines.”**

- 1.4.1 The first and most critical recommendation is that we must recognize that it will take at least a generation to “stop” (that is, stabilize conditions) the climate and global-scale changes we have set in motion, and that it is doubtful that we can ever “reverse” them (in the sense of getting back to baseline conditions of the past few thousand years).
- 1.4.2 We must work to reduce and reverse direct, local human impacts in order to preserve the natural robustness and resilience of reef organisms and ecosystems to survive the inevitable climate stress. This can be done with a combination of enforced regulation, education, and political and economic incentives, but it will not be adequate by itself.
- 1.4.3 We must do a far better job of protecting, monitoring, and understanding those coral reef systems that are NOT threatened by direct local stresses, both to ensure preservation of the genetic diversity and the natural heritage, and to develop a predictive understanding of how continuing climate change affects reefs so that we can make our protection and management strategies as effective and realistic as possible.
- 1.4.4 Finally, we should recognize that complex global problems cannot be addressed on a single issue basis. Not only is international cooperation critical, but we should not allow the obvious importance of coral reefs to divert us from holistic considerations that encompass global change effects on, and the interactions of, other coastal and marine systems.

**1.5 “...other information...pertinent to the discussion.”**

- 1.5.1 The United States is one of only a few countries that has the possessions and resources to develop a comprehensive program of understanding, predicting, and mitigating the effects of climatic and other stresses on coral reefs and other marine systems.
- 1.5.1.1 The Caribbean and Gulf of Mexico is a relatively enclosed region with high population loads, and in almost all areas will reflect a combination of local and regional human stresses with climate-related stresses. It can serve as the “high-to-moderate local stress” component of an ecosystem-based research and monitoring program.
- 1.5.1.2 The diverse U.S. Islands and atolls in the central Pacific are among the most pristine and remote from direct human impacts, and provide both a natural laboratory for documenting the nature and mechanisms of climate change effects, and a potential bio-reserve of global importance.
- 1.5.2 Relatively few new resources are needed to develop and implement a global-scale US comparative program to understand and respond to the effects of climate change (alone or in concert with other stresses)

on coral reefs and their related marine environments and associated ecosystems. Modest additional funding for the USFWS and NOAA for baseline studies, protective enforcement, and management of both the sites and the research and data, would have a major effect if combined with focused coordination of existing coral reef and global change research and funding programs.

**2. Earth system changes and interactions** (*“...how the interplay between climate, the marine environment, and coral ecosystems has changed, and the resultant and predicted effects.”*)

**2.1 Climate change background – a reef perspective**

Climate change is not new; climate has changed between glacial conditions and interglacials (like the present) many times over the past several million years. Figure 2.1 shows detailed records of temperature and the atmospheric concentrations of carbon dioxide and methane over the past 450,000 years, derived from analysis of glacial ice cores. A striking and important observation is that there are stable limits to the oscillations – a range of atmospheric CO<sub>2</sub> values from about 180 to about 280 parts per million bounds the natural system, with similar behavior by temperature and other factors. Other evidence suggests that it has been millions and probably tens of millions of years since the earth system has operated outside of these boundaries.

**Figure 2.1:** Records of temperature, atmospheric carbon dioxide, and methane over the past 450,000 years derived from analysis of the Vostok ice core. Note the consistent highs and lows in the cyclic pattern. J. R. Petit et al. (1999) Nature 399: 429-436



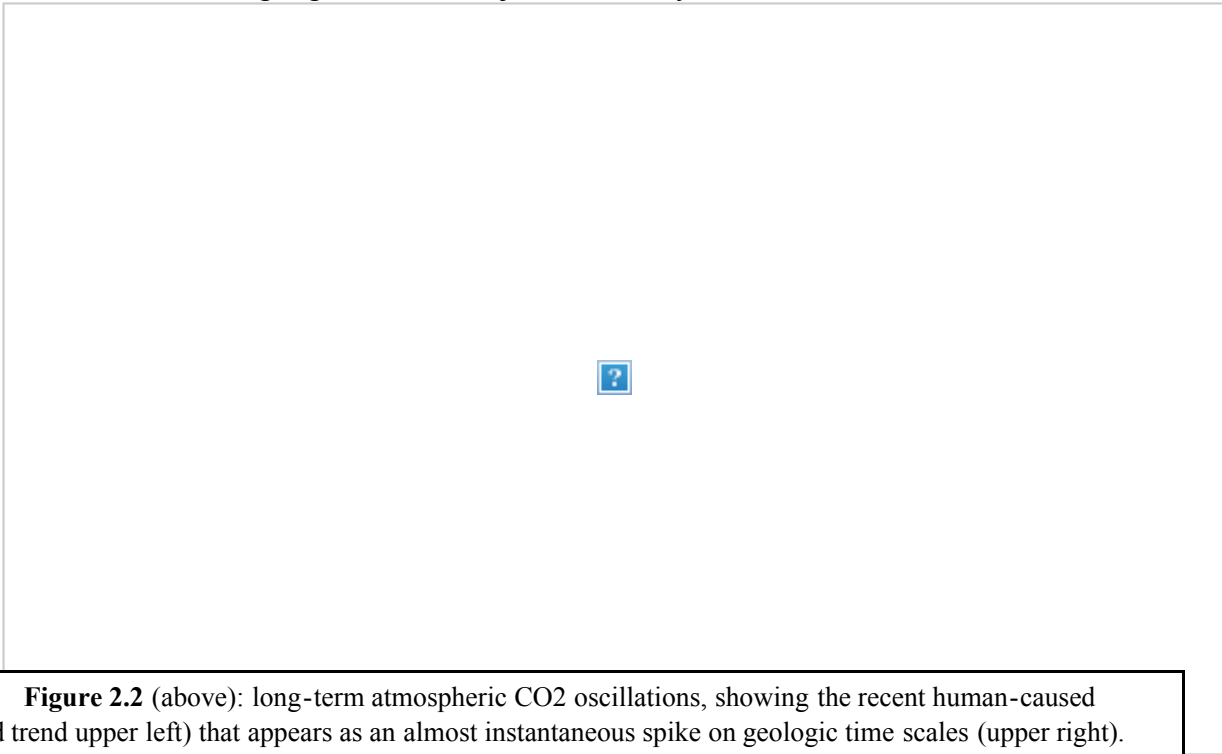
Even within the natural range of variation, the past several thousand years have had a relatively ‘extreme’ climate – it was warmer, with higher atmospheric CO<sub>2</sub> and higher sea levels than all but a few percent of the period for which we have good records. The long-term average natural condition for geologically modern coral reefs is a tropical surface temperature 2-3 °F (1-2°C) lower than the recent past (with even lower temperatures at

higher latitudes), with about two thirds of the present day atmospheric CO<sub>2</sub> concentration, and sea level ~125-250 feet (40-80 meters) below present. From an evolutionary standpoint, ecosystems and organisms were already living close to the global upper limit of past experience.

## 2.2 Environmental changes and results

The recent human-caused increase in atmospheric CO<sub>2</sub> and the increasing temperature and variability is rapidly moving the environment outside of natural evolutionary experience. Figure 2.2 puts into perspective the dramatic ‘spike’ in atmospheric CO<sub>2</sub> associated with the growth and industrialization of human society. Figure 2.3 puts temperature records – measured and inferred – into perspective on a thousand-year time scale. Temperatures of the last few decades have risen well above not only the long-term pattern, but also above the estimated range of uncertainty about the values (displayed by the ‘fuzzy envelope’ around the trend line).

Temperature and carbon dioxide concentration have been emphasized above because these are known or very probable coral reef stresses. Both field and laboratory studies implicate elevated temperatures (along with light and reduced water motion) in the dramatic increase in bleaching events. Elevated carbon dioxide concentration equilibrates with the surface ocean, making it more acidic and thus a less favorable environment for precipitating calcium carbonate – the building material of coral skeletons and reef structures. To these global changes we can add others; it is well-documented that human activities have very substantially altered the nitrogen, phosphorus, water, and sediment cycles as well as the carbon cycle and climate. These other alterations are not necessarily benign with respect to reefs and marine ecosystems – accelerated nutrient cycles are responsible for excessive algal growth and major community shifts.



**Figure 2.2** (above): long-term atmospheric CO<sub>2</sub> oscillations, showing the recent human-caused upward trend upper left) that appears as an almost instantaneous spike on geologic time scales (upper right).

**Figure 2.3** (below): 1000-year temperature record showing historic pattern, uncertainty, and recent

trend.

Mann et al. (1999) GRL 26: 759-762



### 2.3 Problems of prediction

This current and ongoing departure from ‘normal’ conditions has been referred to as the “no analog” earth – we have nothing in either human experience or geologic history that we can reliably compare it with to assist us with understanding and predictions. This is further complicated by direct as well as indirect human alterations of the marine environment. The rapid growth of human population and the attendant pressures for development, especially in the coastal zone, have added local and regional stresses connected with overexploitation, pollution, and direct destruction. These are not alternatives to the global stresses on marine ecosystems; they are additive or synergistic, so that organisms weakened by one stress will be more vulnerable to others.

### 3. **Relative importance of natural variability and human impacts** (“...whether the range of atmospheric and marine conditions and the extent and intensity of coral declines is expected to be from natural climatic cycles and variations or if these declines stem from human-driven factors.”)

The information, and especially the figures, presented in the preceding section contain the answer to the question around which this section is formulated. Figures 2.1 and 2.2 show natural cycles on thousand-year time scales, with Figure 2 illustrating the recent human-driven change in carbon dioxide. Figure 2.3 shows natural temperature variability at 10-100 year time scales, also with the recent displacements from the natural pattern.

These human-driven changes in the climate factors are not only large and rapid, but they take the atmosphere and oceans into ‘unfamiliar territory’ – combinations of conditions not experienced over recent evolutionary history. The changes are both large and abrupt compared to records of natural variations, and coincide very well with the onset of major large-scale coral reef declines.

While these comparisons do not prove that human-derived climate changes constitute the non-local causes of coral decline, the circumstantial evidence is extremely strong, and the argument can reasonably be reversed – if the substantial human-driven changes are not causing the decline, then it is very unlikely that the smaller and more modulated natural fluctuations would be imposing significant stresses.

This conclusion is further supported by results of coral and reef coring studies that indicate that the recent community shifts and mortality are unprecedented in the last several thousand years.

### 4. **Relative importance of climate and other factors** (“...of what importance compared to other factors are climate effects in coral reef declines.”)

#### 4.1 Climate effects, past and present

Local and regional human-induced stresses have taken a heavy and accelerating toll on reefs over the past half-century. nutrient loading, contamination, overfishing, sedimentation, and direct destruction have all been factors in general, but with large geographic variations and a variety of combinations. It seems likely that these local-to-regional human factors were the dominant factors in reef degradation and decline until about 10-20 years ago, although deteriorating climatic conditions may have contributed to overall vulnerability.

Recent past events strongly suggest that climatic factors are increasingly causing widespread degradation in areas remote from major local stresses. Local stresses will remain important, but we are in a transition period from dominance by local stresses with climate stress reinforcement, to predominance of climate related stress, with additional local impacts in many areas.

#### 4.2 Climate effects, present and future

Figure 4.1 connects the record of evidence on past climates with the range of IPCC scenario projections to 2100, for both temperature and CO<sub>2</sub>. Even with the most optimistic view of the future, the trends that have already taken the planet outside of the natural environmental range of the recent geologic past will move it even farther into unknown territory in the coming decades.

An important aspect of these changes is the inertia of the trends. The changes that have been set in motion cannot be easily or quickly reversed; lags in both the earth's geochemical systems and human socioeconomic systems mean that temperature and CO<sub>2</sub> levels will continue to increase for several decades no matter what action is taken to stabilize the earth system. Eventual stabilization is possible if greenhouse gas emissions are carefully controlled, but in the short- to intermediate term we have no alternative to trying to understand and adapt intelligently to the changes that have been set in motion.

**A climate-driven future for earth's ecosystems** --- Figure 4.1 illustrates the possible range of changes in temperature and greenhouse gas concentrations over the present century. Even with the greatest of effort and the best of luck, changes to the lower end of the projected range will probably occur, creating environmental conditions that are unprecedented in recent geologic history. Major challenges include: (1) measuring, understanding, and eventually predicting ecosystem and organism responses to extreme and rapid climate change; (2) separating these responses from other human-driven or independent stresses arising from development or environmental change; and (3) protecting ecosystems, their biodiversity, and the services that they provide to humans from avoidable stresses and insults, to maximize their chances of surviving the unavoidable climate stress. The US is fortunate possess a system of reserves and sanctuaries that can be readily adapted to those ends.

+2°C  
+1°C  
Recent  
average



## 5. General recommendations related to coral reef declines (“...what recommendations would you provide for stopping and reversing these declines.”)

### 5.1 Definition of issues and recommended actions

We cannot expect to stop or reverse the effects of the global-scale changes we have set in motion on time scales of decades. In order to have a positive effect on the ability of all marine and coastal ecosystems (including coral reefs) to survive both increasing direct climatic stress and the much broader associated ecosystem and environmental changes, selective but extensive protection from other stresses (which can be controlled or eliminated) needs to be combined with a substantial improvement in our understanding of stress-response mechanisms and natural limits. (See section 6 below for a specific proposal)

#### 5.1.1 Critical needs

- 5.1.1.1 Establishment and support of research sites and facilities that permit studies of relatively healthy, unimpacted reefs from a variety of natural environments. These areas are essential if we are to establish baselines and identify, understand, and mitigate the effects of climate change. Many marine labs and study sites are in areas so degraded that field research on stress-response physiology and ecology is done on moribund systems and stressed individuals rather than those that are responding normally and could effectively be protected.
- 5.1.1.2 Continued investigation of the nature and effects of non-climatic stresses, how these interact with climate-derived factors, and development of both fundamental and applied understanding of organism and

ecosystem stress responses and how these may be applied to management.

- 5.1.1.3 Effective links to the larger global change and marine/coastal ecosystems communities, agencies and programs, both within the US and internationally – coral reefs are a focal organism, but their problems illuminate larger issues, and any solutions will certainly draw on a broad base of knowledge, experience, and cooperation.

#### 5.1.2 Recommended actions

- 5.1.2.1 Establish a genuinely cooperative, adequately supported interagency program that will develop a network of coral and related ecosystem research and monitoring sites along gradients of both climate change and human stress. Information assimilation and dissemination will be a critical component of this program and its links to other recommended actions. Primary agencies would be the US Fish and Wildlife Service and NOAA, but participation by NSF, ONR, EPA, USGCRP, relevant state governments, and private foundations and NGOs will ultimately be necessary for maximum effectiveness.
- 5.1.2.2 Link presentation of results, output, and new biological and environmental findings to the umbrella programs currently being developed to support such diverse efforts. A particularly promising example is the Ocean Biogeographic Information Systems ([www.iobis.org](http://www.iobis.org)) which links species-level taxonomic and occurrence data to geospatial environmental information.
- 5.1.2.3 Develop more effective links with international non-governmental programs that can serve as impartial networking agents and information brokers. One of the most potentially useful such programs is the Land-Ocean Interactions in the Coastal Zone (LOICZ; [www.nioz.nl/loicz](http://www.nioz.nl/loicz)) project of the International Geosphere-Biosphere Programme (IGBP; <http://www.igbp.kva.se/>), which is currently seeking to develop a US national program contact.

## 5.2 Perspectives on planning and implementation

The nature of the problem we face calls for some modification of the ‘business-as-usual’ approach to both science and government. We are working on a constantly changing, as-yet-unpredictable problem with a time constant very long and a spatial scale very large compared to the problems our institutions were designed to solve. An open, ‘adaptive management’ approach to both the scientific activities and the practical applications of the knowledge acquired is needed, and responsible, informed innovation will be at a premium.

## 6 **Other information and specific recommendations** (“...other information...pertinent to the discussion.”)

This section is devoted primarily to further elaboration on the concept of developing a global-scale research park and biological reserve system based on US territories containing coral reef ecosystems.

Such a system would have two conceptual and design components and two organizational components. The basic concept would be to establish a set of long-term research and monitoring transects and reserves along existing and expected gradients in human-driven local environmental stress and the progression of climate change. The organizational structure would be based on coordinated use of the refuge system of the US Fish and Wildlife Service, and the NOAA Sanctuary program, with additional participation from the NOAA remote sensing and monitoring programs.

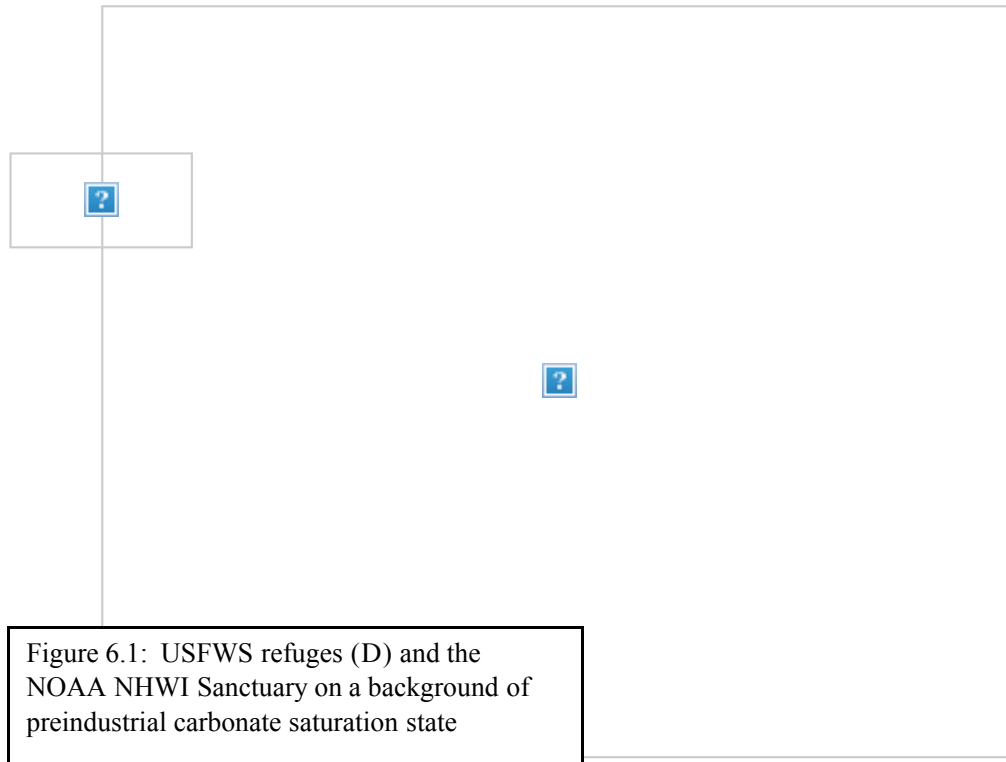
### 6.1 Transect design

6.1.1 Pacific climate transect: The nature of the world’s oceans, the locations of US territories, and the expected pattern of climate change dictate the establishment of two coordinated programs. In the Pacific, US possessions include some of the most remote, unpopulated, and pristine coral reef systems, located in oceanic settings remote from both population and land effects. These cover a large latitudinal gradient, which is particularly important to monitoring climate change, since carbon-dioxide impacts on calcification are expected to move progressively from high to low latitudes and temperature changes will progress in the other direction. The available locations also grade from uninhabited and unimpacted to some regions of human impact and local degradation around the inhabited larger islands of Hawaii, Guam, and American Samoa. The Pacific holdings thus provide an excellent



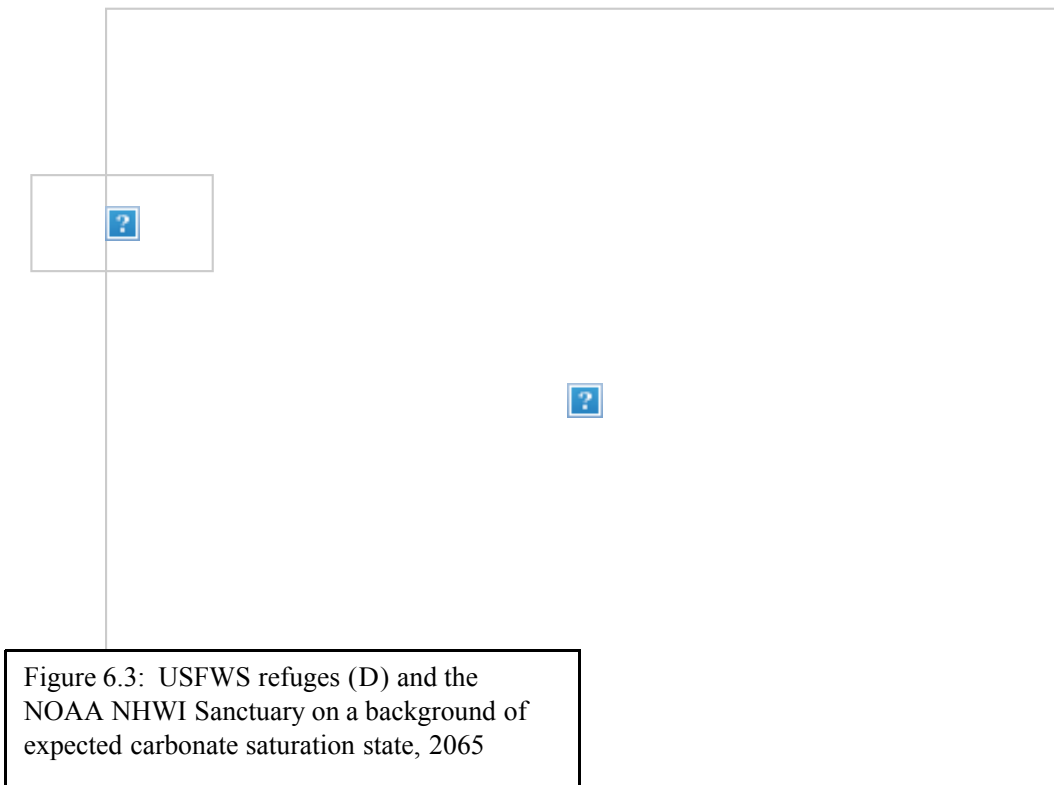
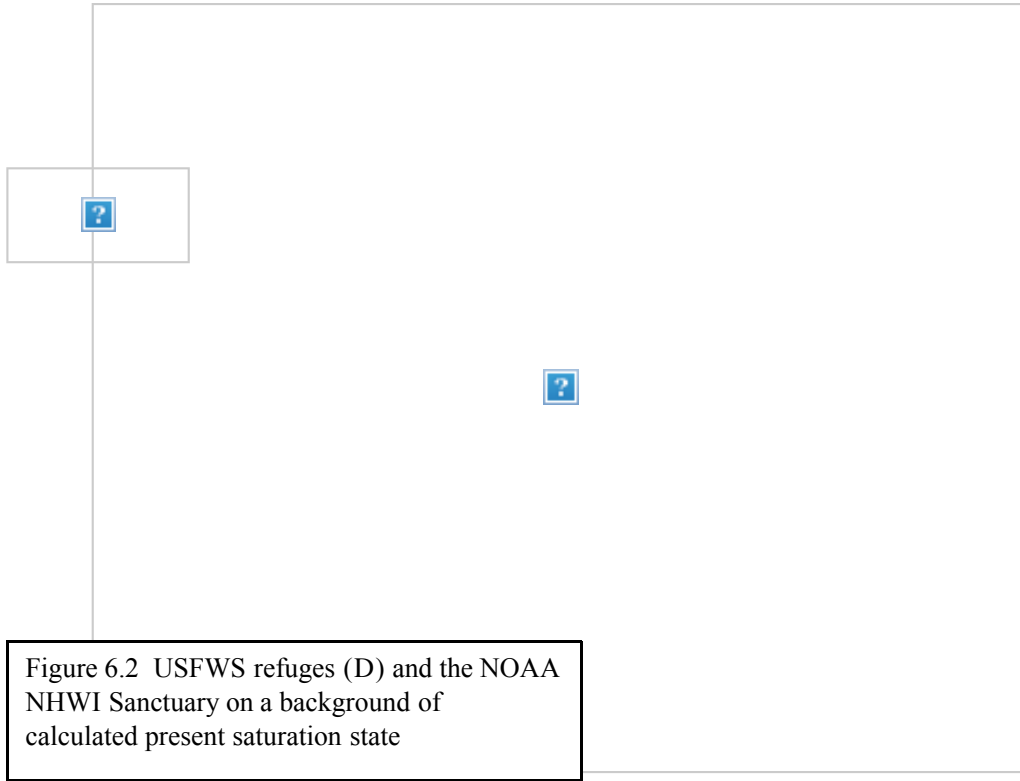
coverage of the climate change dimension, with some overlap into combined local impacts.

The primary components of the Pacific network would be the USFWS refuge system and the NOAA Northwest Hawaiian Islands (NWHI) Sanctuary. Figures 6.1, 6.2, and 6.3 show the island features of the central and eastern Pacific against a backdrop of the calcium carbonate saturation state in preindustrial (mid-1800s), present, and mid-21<sup>st</sup> century times. Saturation state is a measure of the ease with which calcium carbonate is precipitated from the water, and is reduced by rising atmospheric CO<sub>2</sub>. The contours show the expected progression of calcification stress on coral reef organisms over the course of time, and illustrate the opportunities for monitoring and studying similar systems concurrently at different stages of impact development.



**6.1.2 Caribbean/Gulf terrestrial impacts transect:** In contrast to the Pacific, the Caribbean and Gulf of Mexico region is by its nature an interconnected, semi-enclosed basin with strong terrestrial influences, large populations on its coasts, and a high level of reef access and use. Because of the strong, and widely recognized, local human derived stresses, it is a particular challenge to discern the possible role of climate change or large-scale regional interactions, although these must be occurring.

However, the US possessions in that area represent a transect complementary to the Pacific climate transect, in that there is a system of parks, refuges, and protected areas that extend from the high population-high-stress regions of the Florida Keys, Puerto Rico and the USVI to the relatively more isolated Dry Tortugas and the remote Flower Garden Banks. These sites grade from high local and regional impacts to low local and (possibly) moderate regional impacts, and provide a logical complement to the Pacific sites that grade from no local or regional impact to low or no regional, and moderate local effects. The combination permits systematic detection not only of climate change effects, but also of the nature of their interactions with other stresses.



6.1.3 Preservation and management issues: It needs to be stressed that in addition to a critical scientific role, the network of refuges, sanctuaries, and ‘science parks’ would expand and enhance the preservation of biodiversity and living examples of natural ecosystems for future generations.

## 6.2 Institutional and implementation issues

The habitats, ecosystems and marine real estate that would be involved in the proposed development are already in the possession of the US government or one of the states; no capital cost of acquisition would be required. In addition, nearly all of the areas of interest are already under the jurisdiction of an agency with a mission that includes preservation and understanding of the systems, so the basic goals and necessary administrative/legal framework is in place.

Substantial amounts of data, information, and experience are also available from the agency research plans and scientific personnel, although this is not necessarily as readily available to the larger scientific community as might be desired. NOAA projects have been proposed that fit within the overall approach, but as yet there is no programmatic home for these activities.

Integration of the existing facilities and programs into a two-ocean study of reef stress across natural and human gradients could be readily implemented, but would require some new resources and even more new administrative approaches:

- Enhanced budgets for monitoring, protection and enforcement would need to be provided to the lead agencies, along with development of measures of effectiveness, and effective means of communication of results.
- Incentives and mandates for effective cooperation within and between agencies are needed to ensure success; one possibility might be independent funding of a consortium program that would complement but not compete with or replace existing agency programs.
- Two scientific components are required – one that would operate within the lead agencies (either by staff activities or grants and contracts), and another that would require and assist the agencies to provide administrative and infrastructure support for external research programs (e.g., NSF, or possibly international consortia).
- Outreach beyond the conventional limits of the research, environmental management, or ‘coral reef’ communities can provide both broader participation and effectiveness, and political and educational benefits inside and outside the US. NGOs, international, and private partners have potentially important roles to play in realizing the full potential of the approach.

Supplemental Sheet:

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Topical outline:

Requested topics of discussion

1. “...how the interplay between climate, the marine environment, and coral ecosystems has changed, and the resultant and predicted effects.”

The alteration of the carbon nutrient element and other cycles, and the resultant changes in temperature and other climatic factors, has propelled the world into an environmental state that is literally without precedent in the recent geologic record.

2. "...whether the range of atmospheric and marine conditions and the extent and intensity of coral declines is expected to be from natural climatic cycles and variations of if these declines stem from human-driven factors."

Natural cycles are increasingly insignificant compared to both local human effects and human-driven climate change.

3. "...of what importance compared to other factors are climate effects in coral reef declines."

Climate effects are overtaking local human effects as the major driver of reef decline and will become even more dominant in the future.

4. "...what recommendations would you provide for stopping and reversing these declines."

Climate-related declines will not be stopped or reversed on decadal time scales; local human impacts can be controlled and mitigated, which will be necessary to maximize robustness in the face of changing climate. There are critical needs for a better understanding of the nature and course of climate change effects, and of their interactions with other stresses

5. "...other information...pertinent to the discussion."

USFWS and NOAA programs and holding should be components of a coordinated program of monitoring coral reef climate and human across a natural gradient of conditions, making use of the knowledge potential inherent in the programs to protect and preserve ecosystems and the biota.