SUMMARY REPORT

NOAA Atlantic/Caribbean 82 Corals Science Roundtable
June 27, 2012

Local Lead: Dr. Margaret Miller, Ecologist, SEFSC
Chair: Dr. Robert Detrick, Assistant Administrator, NOAA OAR
Rapporteurs: Tara Dolan, CIMAS, Dr. Brittany Huntington, SEFSC, and Dr. Dana Williams, CIMAS

Brief History

On October 20, 2009, the Center for Biological Diversity (CBD) petitioned NMFS to list 83 species of coral under the Endangered Species Act. On February 10, 2010 NMFS issued a 90-day finding warranting 82 candidate species for full status review, 75 in the Indo-Pacific and 7 in the Western Atlantic. PIFSC and SEFSC directors established a seven-member Biological Review Team (BRT) of scientists from five NOAA offices, NPS, and USGS with the mission to assess the status and provide estimates of the risks of extinction for the 82 candidate coral species. On October 28, 2010 the Draft Status Review Report (SRR) was submitted for CIE review. The subsequent comments were responded to by the BRT and the SRR was finalized and published in September 2011.

The review of the status of the 82 coral species is a major undertaking because of the large number and vast geographic range of coral species involved. Therefore, with the approval of a federal court, NMFS and CBD have agreed to an extension of the previously approved deadline for issuing the 12-month finding on this petition to December 1, 2012. NMFS is using this extension to allow additional opportunity for the public to provide additional information that may further inform the 12-month finding as to whether to propose listing for any of the candidate corals. Two public listening sessions and two public scientific workshops are being held, one each in Hawaii and Florida, during which the status revew process will be explained and the public and invited scientific experts will have opportunity to provide additional relevant information on this matter (77 Fed. Reg. 30261-30262, May 22, 2012).

This report is a summary[1] of the second science workshop held on June 27, 2012 at the National Coral Reef Institute, Nova Southeastern University, Dania Beach, FL.

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[1] *This is not a transcript of the event. Please refer to the SRR for the specific findings of the BRT. Also, please refer to the referenced presentations and their associated narratives (where applicable) for specific points made by the panelists. The questions and answers have been paraphrased.*

Science Workshop

Main points from Welcome by Dr. James Bohnsack (NOAA/SEFSC):

- The emphasis of today's workshop is to discuss the science related to the 82 corals in the petition. A separate Listening Session will be held tomorrow regarding the regulatory process.
- Introductions and acknowledgements for Dr. Richard Dodge, Dr. Margaret Miller, Dr. Bob Detrick- moderator.

Main points from Introduction to Workshop by Dr. Bob Detrick (NOAA/OAR):

- Brief explanation of the purpose of the workshop: Open public meeting to solicit advice and recommendations on, and discuss science behind, SRR and to accept public scientific input to assist the listing decision by NMFS.
- Our purpose is to solicit individual advice and information concerning the best available scientific information that should be applied to decision-making related to consideration of listing 82 species of corals under the ESA.
- This workshop was organized by the request of Dr. Lubchenco. It is not part of the normal rule-making process, but it is a unique situation due to the complexity of evaluating 82 species of coral.
- NOAA will use any additional input to ensure that the best scientific information available will be considered as we develop our decision in response to the petition to list.
- The workshop will highlight the science of the 82 corals and has two thematic sessions. The first session concentrates on ecology, general threats, and adaptation of corals and reefs, and the second on climate change threats and impacts.
- Workshop participants can submit written comments either at the workshop or through the NOAA website.
- This roundtable will NOT discuss whether any or all of these 82 corals should be listed. Should NOAA Fisheries determine that a listing is warranted, we will publish a proposed rule in December 2012 and at that time NOAA will invite additional public comment.
- The workshop is not seeking a consensus or recommendations. NMFS wants additional input and will synthesize the new information prior to the listing decision in December, 2012.
- Main points from the presentations will be included in a summary report, but a verbatim transcript is not required and will not be made.

Questions from the audience following Detrick presentation:

None.

Main points from the presentation "Overview of the BRT process, results, and conclusions" by Dr. Margaret Miller (NOAA/SEFSC and BRT member):

- Acknowledgement of the seven BRT members and the numerous subject matter experts who provided scientific input into the process through in-person meetings, conference calls, emails, and discussions at scientific meetings.
- Threats: the evaluation of threats was divided into a ranking of negligible/low/medium/high and were evaluated on all stages of the coral's life history.
- Three main threats were identified: (1) Ocean warming; this is already occurring with mass bleaching events that have led to massive mortality of corals, (2) Disease; coral disease has led to decreases in abundance and diversity, and (3) Ocean Acidification; rapidly accumulating research reveals solid evidence for reduced calcification by corals in high CO_2 conditions.
- The species question: "Is the candidate a species?" Coral taxonomy is based on morphology, which can change based upon the environmental conditions of its habitat. Therefore, morphologically-based taxonomic descriptions may not correspond to ESA species definition of 'interbreeding but distinct gene pool'. The BRT chose to accept the morpho-taxanomic species in the list unless clear genetic or life history evidence indicated to the contrary (several *Montipora* spp. and *Pocillopora elegans*).
- From the IPCC AR4 report, the BRT adopted both the "foreseeable future" date of 2100 (time frame of well-vetted climate predictions available), and the qualitative likelihood scale of risk of exceeding the Critical Risk Threshold. This scale allows for the display of both likelihood and a measure of certainty.
- Outline of the method for voting and characteristics of the results (means, measures of uncertainty, range, mode, etc.).
- Brief summary of the strengths and limitations of the BRT approach, which are listed in the SRR.

Questions from the audience following Miller presentation:

* There were no registered speakers for this session.

1) Question (R. van Woesik, FIU): Can you walk us through how 10 votes were assigned by each member of the BRT?

Answer (M. Miller): The team went through each species and a vote was held for each individual species after review and discussion of available information for that species. Each person was allotted 10 votes/points per species to allocate across 8 categories assessing threat risk. These votes were summed across the 7 members and then outcome was discussed and particular factors that affected members' voting were articulated and recorded. There is no consensus/repeatability among how each BRT member allots their points

2) Question (M. Chiappone, NOVA): Can you comment on how these species were selected in the first place? And second, how was it determined that there was enough info. to move forward?

Answer (M. Miller): The BRT was not charged with assessing why/how these species were selected. From a NOAA perspective, since these 82 species were petitioned, they must be considered.

(J. Moore, SERO): NOAA was actually petitioned for 83 species based on IUCN listing and whether it occurs in US jurisdictional waters. After the 90 day determination, it was decided that the one of these species (*Oculina varicosa*) did not warrant further consideration. The remaining 82 species were included in the status review. The petition alleged that the 83 species were of high risk ranking by IUCN and occurred in US waters.

3) Question (A. Kusahmaro, BGU): How was coral morphology incorporated in risk estimates for threats?

Answer (M. Miller): Many of the responses to threats (risk) were actually considered by functional group, genus, or family of coral because of limited information/data availability at the species level, yet the listing process dictates that the determinations must be made at the species level.

4) Question (A. Baker, RSMAS): What was the degree of biological familiarity among the BRT members with the 82 coral? How much actual personal experience with each species did the team members have?

Answer (M. Miller, SEFSC): Dr. C. Birkeland was a huge asset to the team for personal knowledge of taxonomy and ecology of many of the Pacific species. Cross-basin familiarity within the BRT team was somewhat limited. Our representation of familiarity of the 82 corals collectively was reasonable and we consulted with experts outside of the BRT. These experts did a lot of validation of occurrence reports for the team.

5) Question (A. Chavez, NOVA): Why was a voting method was used rather than a mathematical risk estimate?

Answer (M. Miller): A quantitative population viability analysis would be ideal. However, lack of information and time prevented population viability models from being feasible. ESA listing protocol calls for the use of the 'best available information' and that was simply extremely limited at the species level and would have limited the value of mathematical analyses even if time had allowed.

6) Question (J. Fisch, RSMAS): Is there a measure within the report about how much information was available for each species to compare with what the final risk assessment ranking was?

Answer (M. Miller): We did not quantify or rank the adequacy or inadequacy of available information for each species. I would assume that for species with more information, you would find less variance among the scores.

7) Question (B. Dietrich): Of the 82 species, how many had good genetic basis for species identification? And, how many had real issues with cryptic speciation or clades?

Answer (M. Miller): There were two or three groups within the *Montipora* genus that were lumped into larger clades due to published results (showing lack of genetic distinction), which resulted in a lower risk assessment because the geographic range, population etc. were increased through lumping. When species identity was in question, as it was with *Porites pukoensis*, the species was ranked both as a unique species (resulting in very high risk) and as part of a larger clade (resulting in very low risk). Less than 10% of the 82 species received these alternate classifications.

8) Question (R. van Woesik): How do the BRT rankings compare with the IUCN rankings?

Answer (M. Miller): We haven't directly compared the two. However, their method is based solely on geographic range and broad regional estimates of habitat loss. Our result would likely differ since we tried to incorporate species-specific ecological characteristics into the BRT analysis. However, no direct comparison was made.

(R. Aronson): I participated on the IUCN rankings, and I know the *Montastraea* species complex was ranked as high risk for the IUCN as well.

9) Question (S. Pannaman, Sierra Club): What methodology did you use to evaluate whether sea surface temperature increased?

Answer (M. Miller): The IPCC AR 4 report was used for overall climate projections, and some recent scientific publications used for assessing temperature and ocean acidification.

10) Question (T. Tweaton, Sierra Club): How often will the corals be re-evaluated as more information comes in?

Answer (J. Moore): The current evaluation must fall within a statutory timeline following a petition. The deadline for the current review was Dec 1, 2011 but was extended 12 mos due to the unprecedented scope of this review. For any species determined to warrant listing we issue a recovery plan and the status will be reviewed every 5 years. Part of this process encourages continued research for the listed species.

Thematic Session 1a: "General Coral Reef Ecology and Threats"

Main points from the presentation "BRT Summary regarding General Coral Reef Ecology and Threats" by Dr. Margaret Miller (SEFSC and BRT member):

- Specific ecological information on most of the species was limited, including population, status, trends, vulnerability. Adequate information on population status and trends were available for the Montastraea annularis complex species, and useful rarity and population estimates are available for several Pacific Acropora species.
- Extinction threats are influenced by scale and act on multiple scales.
- Extinction threats rankings were based on projection of "status quo" and anticipated response by coral.
- Many extinction threats should be considered together as they are interactive, yet quantifying these interactions is challenging.
- Caribbean species were generally ranked at high risk due to small geographic range size and severe disturbance history in this region.
- There is little clear evidence to consider the adaptation/acclimatization of specific-species to ameliorate extinction risk.

Questions from the audience following Miller presentation:
Held to the end of this thematic session.

Main points from the presentation "Biological and physical controls on coral reefs" by Dr. Rich Aronson (Florida Institute of Technology):

- The challenge for the BRT is to establish the relationship between threats to reefs and species-specific threats. A specific goal of this presentation is to connect ecology to extinction threats.
- It is well established that coral reefs have overall experienced biologically significant decline (80% decline in coral cover in absolute terms) in the Caribbean caused by several successive, interacting and reoccurring threats such as: an initial drop in acroporids from white band disease, El Niño, *Diadema* dieoff, and bleaching.
- Controversy exists on the role of more localized (albeit often broadly distributed) factors such as macroalgal growth, herbivory, and possible phase-shifts.
- Although there is evidence that macroalgal dominance is detrimental to coral reefs for multiple reasons, most Caribbean reefs (examples used included reefs in the FL Keys and USVI) are not dominated by macroalgae, regardless of the definition of dominance used.
- There has been a decoupling of the trajectories of coral and macroalgal cover over time. Benthic cover components other than coral or macroalgae (including but not limited to crustose corraline algae, turf algae and bare substrate), appear to oscillate opposite macroalgae, but coral cover remains relatively stable at low levels in the Florida Keys.

Thus, relationships between corals and macroalgae are not tight as thought.

- Primacy of the physical: Regional and global threats such as disease, ocean warming, and acidification are the most influential processes, probably exceeding the influence of local threats such as macroalgal cover.
- The BRT has the responsibility to evaluate and rank extinction risks on a species-specific scale, as well as multiple geographic scales.
- Predator outbreaks improperly categorized in SRR; should be moved to Category II (local but widely distributed) from Category III (local impact only).
- Included in the consequences of global/regional forcing factors is the homogenization of coral assemblages at local, subregional and regional scales. Species-specific declines, such as the decline in acroporids, contribute to homogenization.
- Temperature effects will exert greatest influence in the coming decades. The challenge is to incorporate biological traits of individual species into quantitative evaluations of extinction risk due to temperature and its component and related threats (disease, increased sea surface temperature, bleaching), when alternative stable states are unknowable, if indeed they exist.

Questions from the audience following Aronson presentation:
Held to the end of this thematic session.

Main points from the presentation "The role of seaweed competition and phenotype-environment mismatch in the coral reef death spiral" by Dr. Mark Hay (Georgia Institute of Technology)

- Reefs today are no longer like reefs from 30 years ago. Stressors are different and likely will be different 30 years from now. The most important ones may be the ones we don't know about yet.
- We can't save corals by focusing on corals, the ecosystem needs to be 'fixed'.
- Corals in the Caribbean don't show the same levels of recovery as Pacific corals--yet. Is the Caribbean anomalous or an indicator of the future?
- Local management may be effective in "buying time" from global stressors.
- The removal of herbivores globally from reefs trumps nutrient loading as a threat to coral reefs.
- The coral reef decline is a consequence of limited grazing. Greater grazing at least boosts some aspects of coral condition, such as growth, recruitment, etc.
- Fiji experiments show coral in direct contact with macroalgae dies but not from shading or mechanical abrasion or proximity. Instead it is the hydrophobic allelopathic compounds (oils) in the macroalgae in direct contact with coral that cause tissue death.

- Corals differ in susceptibility to specific compounds in different algae and macroalgae species vary in their potency to kill corals.
- Fish herbivores do not graze all species of algae equally. Often the most potent algae are only consumed by a single species of fish. The limited diet breadth of most herbivores makes herbivore diversity extremely important to maintain control of seaweeds.
- Chemical recognition between coral, specific gobies, and macroalgae to favor coral survival suggest a highly evolved relationship.
- MPAs reduce the stress imposed by macroalgae by increasing herbivore abundance and diversity resulting in reduced occurrence of direct contact between algae and coral.
- However, MPAs are not enough because export of larvae into adjacent areas are unlikely both because larvae do not recognize it as suitable habitat and even if they do settle they are less likely to survive in the degraded non-MPA habitat.

Questions from the audience following Hay presentation:
Held to the end of this thematic session.

Public input with roundtable discussion from Drs. Miller, Hay, and Aronson
*****There were no registered speakers for this session.

Questions from the audience:
1) Question (S. Pannaman, Sierra Club): If corals have declined in 80% over 25 years in the Caribbean, what is the expectation for the next 25 years?
Answer (R. Aronson): I would expect further declines, but things cannot get much worse. Taking the view of declines in coral cover as a percent of a percent is misleading. Biological meaning is better inferred from absolute change. **(M. Hay):** I don't think the function of remant pieces of coral reefs in the Caribbean will allow corals to recover in my lifetime. When Caribbean reefs become degraded, they tend to stay that way. The reefs of the Caribbean haven't been very resilient. **(R. Aronson):** There is some evidence of rapid reversals of some of these phase shifts: Discovery Bay, Jamaica for example. The recovery of an urchin favored a rapid recovery of staghorn corals, but in a restricted small area.

2) Question (K. Banks, Broward Co): Macroalgal change has been uncoupled from coral change, but can the coral declines be truly attributed to warming?
Answer (R. Aronson): The link between coral disease and historical declines is a strong one. The primary cause of many coral die-offs is disease, but it is probably not the sole cause. There is a history of bleaching-related mortality. There are many interacting stressors; you cannot pin decline of corals on a single factor. We need to determine what are the more prominent

causes and try to rank them.

3) Question (B. Ruttenberg, NOAA): If resilience needs to be tied to resistance, and resistance is favored by diversity, which the Caribbean lacks, how can we compare basins?
Answer (R. Aronson): The issue of functional redundancy is also bound up with traits of corals in the Caribbean versus more broad regions. **(M. Hay):** The species diversity is higher in the Pacific, but trait-diversity is not necessarily greater (only four of MANY herbivorous fish species eat macroalgae in Fiji). We can make arguments that the Pacific is more resilient, yet we have examples of how small-scale fishing pressure can make an area in the Pacific resemble the degradation seen commonly in the Caribbean. Low levels of take in the Pacific can be catastrophic.

4) Question (Gregory, Univ. FL Sea Grant): El Niño seems to be coincident with disease outbreaks and Caribbean declines? Why?
Answer (R. Aronson): The 1982-83 El Niño did not cause a serious coral decline. There is some evidence that higher sea surface temperatures (SSTs) may be driving white band disease. **(M. Hay):** 1998 El Niño caused intensive, wide-spread bleaching due to high SSTs. Its not the El Niño that's important, it's the elevated SST. This may all be triggered by changes to microbes on the coral holobiont under elevated SST.

5) Question (A. Baker): Gobies seem to protect corals from algae, can we expect that widely?
Answer (M. Hay): The gobies mentioned are very specific, perhaps regionally confined.

6) Question (R. van Woesik): Are MPAs doing better than the non-MPAs in Fiji? Where would MPAs be best located on a regional scale?
Answer (M. Hay): Due to ocean-ownership (local control) common in Fijian culture, it's easy to evaluate the effects of MPA as a management strategy and how the impacts of local governance influence MPA success. Much of the noise regarding MPA performance is due to enforcement. Any place where local control is part of the culture, MPAs are more likely to be successful.

7) Question (J. Bohnsack, NOAA): Jack Baur suggested *Diadema* disease came from the Panama canal and correlated with high temperatures which stress echinoderms. Could a similar occurrence have happened with the corals in 1972 with white band disease?
Answer (R. Aronson): Paleontological evidence suggests that the kinds of things that have happened on Caribbean reefs in the past 30 years are novel at least with regard to the past 30,000 years. It is hard to get information as to where the white band disease erupted. Many scientists originally mistook white band as bleaching.

8) Question (M. Chiappone, NOVA): It seems like there may be rare, pulsed recruitment for the establishment of Caribbean spawning corals. Hence, once they die back, they aren't going to come back anytime soon. Is this corroborated by the geologic record?
Answer (R. Aronson): The size of most Florida *Montastraea* colonies suggests that they are the same age based on size. We are all wondering why they all spawn every year when it rarely results in successful recruitment. We don't know what it is that makes it a good year for *Montastraea*. If you have a species that only successfully recruit every few decades---a serious catastrophe in the interim can lead to extinction. **(M. Hay):** Land use change may be influencing the success of coral recruitment. Research done on fish responses to water running off land that has undergone land use change suggests land use may be more connected to reefs and recruitment success (at least for fish) than is currently known.

9) Question (Clark, Cry of the Water): If corals may be moving north due to climate change, shouldn't we be protecting the large corals at the northern edge of their boundaries?
Answer (R. Aronson): I agree. I would like to protect everything. I don't know that *Montastraea* is moving northward. There is a limit to how far Caribbean corals could move northward due to geochemical limitations. Preserving corals at the margins of the range will probably not facilitate general reef recovery.

10) Question (A. Chavez, NOVA): Could the lack of correlation between coral declines and macroalgal abundance be due to the very low abundance of corals currently?
Answer (R. Aronson): That's a strong possibility. **(M. Hay):** I think experiments could answer that question.

11) Question (S. Pannaman, Sierra Club): Are the fish in the Caribbean around what's left of the corals suffering the same declines as the corals?
Answer (M. Hay): Today in the FL Keys, the picture is less clear than it was 30 years ago. Corals are in dramatic decline, macroalgae is low, but there are lots of herbivorous fish.

Thematic Session 1b: "General Coral Reef Ecology and Threats: Adaptive potential" (con't)

Main points from the presentation "The extinction risk of corals: the past, the present and the future" by Dr. Robert van Woesik (Florida Institute of Technology):

- The BRT seeks to understand the past and present traits that confer extinction risk.
- Resilience to thermal stress is related to biological traits and ecological processes. Certain physical and morphological traits confer resilience to thermal stress, but there

are also evolutionary/adaptive processes at work which might influence the fate of coral species reviewed by the BRT.

- Based on a hypothetical 3 month summer thermal stress test, we scored the traits of each taxa that fared well and poorly to come up with 'resilience score'. Some results were counter-intuitive: for example *Montastrea* species had low vulnerability scores despite reports of decline whereas *Pocillopora*, *Stylophora*, and foliose *Pavona* are deemed most vulnerable in Pacific fauna.
- Physical traits conferring resilience include morphology: Massive corals are more tolerant to thermal stress than branching.
- The paleontological record provides insight to biological processes which may be at work. 3.2 million years ago when the Caribbean basin separated from the Pacific, increased thermal variability caused regional and global extinctions. Pacific taxa that went extinct in Caribbean are deemed most vulnerable currently; namely Pocillopora, Stylophora, and foliose Pavona. High abundance does not necessarily confer increased resistance to extinction.
- When these results were compared to IUCN rankings, there were disconnects. This might be because IUCN rankings are based on static maps and do not take into account biological traits.
- Oceans are not homogeneous. The paleontological record shows that different regions have different patterns of sea surface temperature anomalies and differences in frequency of return.
- Organisms which face high frequency anomalies of a specific stressor are more likely to adapt to that stressor.
- Conservation measures must consider environmental range occupied by a species. Some areas may serve as refugia. It must also consider variability experienced and key thresholds.
- Based on our knowledge that biological traits influence vulnerability to climate change, we can infer that some species will adapt and others will not. For example, *Montastrea* will likely persist.
- Physical processes will also influence variability. The Caribbean has faced consistent stressors, it will be more resilient to increased magnitude and duration of the same stressors. We can infer the Pacific is going to be hit way harder [by thermal stress] because stressors have not previously been as prevalent.

Questions from the audience following van Woesik presentation:
Held to the end of this thematic session.

Main points from the presentation "Coral nutrition, defense and adaptation to changing

environment: the role of its associated microbial community" by Dr. Ariel Kushmaro (Ben Gurion University):

- Corals are complex animals. The coral holobiont and coral mucus contain many things including: bacteria, protists, and algae.
- Change in environmental conditions and coral physiology result in changes to mucus which leads to microbial changes.
- The microbial community contributes to coral health as a direct food source, antibacterial production, and nitrogen fixation.
- Temperature, nutrients or other environmental stress can increase the virulence of a pathogen that results in coral disease.
- Environmental change can induce change in the holobiont microbial community that can facilitate adaptive change in the the coral to survive the environmental stress more readily than a genetic change.
- Within the coral mucus, antibacterial production and activity varies by coral species and can fluctuate with temperature.

Questions from the audience following Kushmaro presentation:
Held to the end of this thematic session.

Main points from the presentation "Contribution of algal symbionts (*Symbiodinium* spp.) to the adaptive capacity of reef corals" by Dr. Andrew Baker (University of Miami-RSMAS):

- Adaptive capacity of the coral holobiont is comprised of adaptation of the coral animal, microbial community, and symbiotic zooxanthallae.
- Significant diversity exists within the genus/clades of *Symbiodinium*.
- Reef-building corals are obligate symbionts with zooxanthallae, yet can adaptively shuffle their symbiont community through bleaching to adapt to changing environments. However, this shift to more-tolerant symbionts has been shown to be short lived in at least some cases.
- Clade D is the most thermally tolerant *Symbiodinium* clade; adaptive bleaching to favor Clade D can increase thermal tolerance (1-2 degrees) of a colony over short timescales.
- In response to warming SST, some coral species are more capable of adapting their symbiont to more thermally tolerant clades than other coral species.
- Most coral host diverse clades of symbionts. Coral have more ecological redundancy in their symbiont compositions than previously thought.
- There are functional trade-offs for hosting tolerant clades (e.g. growth, reproduction).
- Corals with higher density of symbionts in them are more susceptible to bleaching. Hence, there is the potential that reducing eutrophication (which increases symbiont abundance within the coral host) could confer bleaching protection.

Questions from the audience following Baker presentation:
Questions were held to the end of the thematic session.

Public input with roundtable discussion from Drs. Van Woesik, Kushmaro, and Baker:
* There were no registered speakers for this thematic session.

Questions from the audience:

1) Question (L. Fisher, Broward Co): When is adaptation no longer occurring in terms of acidification?:
Answer (R. van Woesik): Adaptation will continue to matter. It doesn't mean that it will save the species. **(A. Baker):** We should be studying responses to acidification. There will likely be adaptive responses to both thermal stressors and acidification. There is going to be adaptive responses to lower pH; there is some evidence that corals can respond to pH changes.

2) Question (J. Moore, SERO-NOAA):_Is there a point at which the rate of adaptation is not keeping up with the rate of change from environmental change?
Answer (A. Baker): We are at that point already. Adaptive ability is not keeping up. Corals are being out-paced. **(R. van Woesik):** I disagree. It is regionally-specific. Some place are doing fine and others are not. **(J. Bruno):** There are limits to thermal adaptation; biochemistry tells us you can only evolve so much.

3) Question (T. Adam, FIU):_I am surprised *Pocillopora* is a susceptible, high risk species according to Dr. van Woesik? Do extinction rates presented in his paper take into account growth rate differences between species?
Answer (R. van Woesik): *Pocillopora* is widely distributed, but it is also the first to die when thermal stresses come through. Large geographic-scale disturbances wipe out the population when severe thermal stress events occur. Though *Pocillopora* does have high growth, if the population is lost entirely due to thermal stress, there will be no colonies left to grow. Hence, *Pocillopora* was ranked as high risk. Some of these species, despite their prevalence and reproductive productivity, are still some of the least tolerant to thermal stress. You still need to be there to be able to disperse and recover from severe thermal stress events. **(A. Baker):** I am concerned that when we rank these species in terms of their response to coral bleaching, the approach will miss a lot of the variability inherent within the species.

4) Question (M. Hay, Georgia Inst Tech): Can you distinguish cause from consequence in the changes on microbial surfaces of corals? Is the coral manipulating its microbes or are the

microbes taking advantage of coral weakness to become more virulent?
Answer (A. Kushmaro): We really don't know yet. We can detect change, but not yet so readily cause and effect. We are in the beginning stages of learning about the immune response. Corals can change the composition of their mucous, but also bacterial communities may take advantage of different environmental conditions.

5) Question (M. Miller, NOAA-SEFSC): Dr. van Woesik, can you summarize the traits that make *Montastraea* low risk? *Montastraea* is susceptible to disease, which might be the trouble with this species. Were there any disease-related traits included in your study to assess risk?
Answer (R. van Woesik): Refer to the paper to see what traits were specific to *Montastraea*. I don't believe we included any disease related traits. The difficulty in discerning the effects of diseases is how little we understand of the coral immune response. We did not feel confident enough in available information to include this in the paper. Hopefully, we will be able to include this in future analyses when more information becomes available.

6) Question (J. Moore, NOAA-SERO): If a particular species has shown adaptation to a particular stressor, does that imply an ability to adapt to an additional stressor?
Answer (R. van Woesik): Certainly there are synergistic responses, but few have been empirically shown.

7) Comment (R. Aronson, FL Tech): The *Montastraea* complex is of concern because BRT and IUCN ranked these species as vulnerable, but van Woesik's paper did not. We may need to consider the evaluation of these rankings within the two ocean basins separately.

8) <u>Question (L. Krimsky, FL Sea Grant):</u> If higher abundances of zooxanthellae (due to nutrient-addition) correlate with higher bleaching, what mechanisms might be accounting for this? What evidence has been found thus far?
Answer (A. Baker): We are still exploring whether raising corals with greater abundances of zooxanthellae really affects thermal tolerance. It is well documented that corals increase density in symbionts in response to nutrient addition, but we haven't tested if manipulating symbiont densities by nutrient addition can confer enhanced thermal tolerance. Those studies are in progress.

9) Question (M. Hay, Georgia Tech): How does geographic range of common species affect susceptibility to disease and extinction potential? Are there contagion models for this?
Answer (M. Milller): Both high population density and other stressors such as temperature have been shown to increase impact from some diseases. **(R. van Woesik):** The models used assume these diseases to be contagious, but important coral diseases may not be. It is likely to

be more complex. These diseases may be up-regulated from thermal stress, not transmitted.

10) Question (B. Detrick): Do we know anything from the geological record on how corals managed to adapt and survive past major extinction events?
Answer (R. van Woesik): Corals have been around for 2 million years. However, the rate of change in the environment is now one hundred times faster than in the past. Our ability to learn from the past is limited. We do know that in the past there were remnant coral assemblages where their were no reefs, but eventually reef-building species came back. **(R. Aronson):** There have been 5-10 million year lags between reef-building coral epochs, when environmental conditions were not favorable to reef accretion. This might have been due to limited physical habitat availability. **(A. Baker):** Corals have been experimentally grown in extremely high CO_2 levels. Corals did survive and reproduce but lost their ability to calcify. Once CO_2 conditions were lowered, the corals regained the ability to calcify. **(M. Medina):** Reefs in the fossil record are not always formed by scleractinians but by molluscs and other groups .

11) Question (B. Ruttenberg, NOAA-SEFSC): I like the idea of what traits are more likely correlated with extinction risk. There is context dependency in those traits. How do we evaluate context-dependency and the utility of these models?
Answer (R. van Woesik): We need to take it one step at a time and evaluate each trait experimentally. Patterns may not be regionally consistent.

12) Question (T. Adam, FIU): Can you take Dr. van Woesik's extinction probability model and test it against historical extinctions in the Caribbean?
Answer (R. van Woesik): Once we get dynamic range distribution maps that are updated and dynamic, I think this will be possible. Maybe over 5-10 year increments we can start getting a clearer picture.

Thematic Session 2: "Climate Change and Climate Impacts on Coral Reef Ecosystems"

Main points from the presentation "BRT Summary regarding Climate Change Impacts" by Dr. Margaret Miller (SEFSC and BRT member):

- CO_2 is rising and is possibly the highest it has been in 24 million years due to human population increase combined with increased per capita emissions. CO_2 emissions are presently meeting or exceeding the IPCC AR4 worst case scenario.
- Rise in SST has already caused widespread bleaching and mortality; globally 40% of reefs have been affected by bleaching between 1997 and 2008.

- SST is expected to increase 0.8 °C by 2030 and 2.8 °C by 2100.
- Warming is a threat to all coral life stages, other impacts of warming include disease, impaired reproduction, and increased ocean stratification and oligotrophy.
- In addition to warming the ocean, increased CO_2 reduces carbonate concentrations and therefore pH leading to ocean acidification.
- Ocean acidification decreases cementation on reefs and increases erosion
- Ocean acidification also impairs reproductive success including its impact on crustose coralline algae, which has an important role in coral settlement, as well as altering larval settlement cues.
- The impact of global climate change varies geographically. It is lowest in the Indo-Pacific and higher in the Eastern Pacific and Western Atlantic Caribbean area.
- Ocean warming and ocean acidification outweigh other climate threats in their potential to pose an extinction risk.
- Climate change is pervasive and therefore threatens the best managed and most remote reefs.
- Climate change is the major reason that most of the 82 candidate coral species are 'more likely than not' to fall below the critical risk threshold by 2100.

Questions from the audience following Miller presentation:
Questions were held to the end of this thematic session.

Main points from the presentation "Coral reef responses to global climate change: A genomic perspective" by Dr. Monica Medina (UC-Merced)

- The classical view of the coral is evolving as the fields of cell biology and genomics advance.
- Genomics allow the ability to look at all the genes being expressed as a proxy for phenotype.
- We've developed a conceptual framework of which genes are differentially expressed when thermal conditions change. Genes involved in calcium homeostasis were found to be affected by thermal stress.
- Once corals recovered from bleaching, all corals converged on the same *Symbiodinium* genotypes.
- Genes are species-specific in the developmental onset of coral-*Symbiodinium* interactions. However, response to thermal stress and recovery is more conserved (i.e. similar) among corals of differing lineages.
- There is a need to shift away from this dual partner (i.e. coral and zooxanthellae only) perspective towards a "holobiont perspective" including prokaryotes, protists, fungi, and viruses.

- Corals host an extremely rich microbiotic community, creating a complex microbiome.
- Microbiotic communities occupying healthy corals differ significantly from those on diseased corals.

Questions from the audience following Medina presentation:
Question were held to the end of this thematic session.

Main points from the presentation "Effects of ocean warming on coral populations and communities" by Dr. John Bruno (UNC-Chapel Hill)

- Global warming is disproportionately affecting the ocean, which is warming at all depths. Even the deep ocean is an important heat sink. However, gradual relationships depicted in classical climate graphs typically hide a lot of variability. This has a number of implications for coral because, among other things, relationship exists between ocean temperature and the prevalence of certain diseases.
- There is a lot of spatial and temporal variability in how the ocean is warming. Due to the strong relationship between sea surface temperature and *in situ* reef temperature, satellite sea surface temperature data can now be used to explore increasingly fine scale patterns of temperature anomalies through the metric of cumulative heating weeks.
- Hot spots of varying sizes pop up and last a few days to a few weeks. More than half of these are less than 50 km^2 We really don't know to what extent these hot spots are temporally and spatially auto-correlated. At relatively small scales these hot spots move around in space over time. It is not yet easy to predict at fine scales which reef will warm in which year. However, at larger spatial scales, there is likely positive auto-correlation. Large regions that have warmed in the past are likely to warm again.
- We may have missed these spatio-temporal effects at fine scales in the past when most studies focused on broader trends. Using means hides variability, resulting in an assumption of homogeneity. Really the environment is heterogeneous to a larger degree than was previously thought. Now that we have the technology to map these finer scales, we are discovering this.
- One problem with focusing on broader trends is when you take IPCC projections and reconvert them into predictive maps of warm anomalies, it results in predictions of massive hot spots which may not be the full picture because these IPCC projections are based on averages which hide fine scale variability. Warming is exceeding IPCC scenarios, and lagging heating.
- High variability at small scales may result in localized differential adaptation to thermal stressors.
- Species may shift their ranges in response to changing thermal regimes. The 'velocity of climate change' is a means to characterize how far/fast a species must shift to maintain

a suitable thermal habitat.

- Ranges shift ability is also moderated by the natural spatial gradient in temperature: such as steepness of the thermal gradient across space, proximity to and accessibility of thermal refugia. For example, in the tropical ocean 20-100 km/decade range shifts must occur to keep up with climate change. Seasonal range shifts are not well known, but affect phytoplankton cycles.
- We may be overly optimistic in our belief in how protected areas mitigate threats to reefs due to thermal regime change. No-take reserves may not prevent coral or fish loss because they are static in location, whereas suitable thermal habitat is shifting.
- Meta-analyses have quantified weekly anomalies, and found positive relationship between thermal stress and loss of coral cover. However, no difference in susceptibility of corals to thermal stress from sea surface temperature anomalies was found in terms of local management or lack thereof. Ultimately, MPA's may help improve coral cover in a variety of ways, but enforcement is key.

Questions from the audience following Bruno presentation:
Questions were held to the end of this thematic session.

Public input with roundtable discussion from Drs. Miller, Medina, and Bruno:

Registered speakers: M. Chiappone will submit written comments.

Questions from the audience:

1) Question (M. Hay): Looking at the variance rather than the mean is extremely important. Has anyone examined variance in MPA performance relative to enforcement?
Answer (J. Bruno): Enforcement is a tricky question, since information is sparce, and often self-reported. Our analysis did not

2) Question (J. Moore): Was the correlation between MPA age, when bleaching occurred, and the response to bleaching explored in the success of MPAs to benefit corals?
Answer (J. Bruno): The survey time was incorporated. The age of the MPA was not incorporated, but we do know that the age of the MPA is important in determining benefits to corals. The difficulty with age is that for many MPAs, there is little information about their date of establishment, exact location, and management plan. It can be difficult in MPA studies to get around sampling bias and MPA siting bias, but the fact that these surveys were designed to detect MPA efficacy, but rather about bleaching, helped. **(R. Aronson):** MPA establishment

isn't uniform. Rather, there is a siting bias to where MPAs are placed. Some are placed in nice areas to preserve them and some are placed in more degraded area in an effort to help them recover. **(J. Bruno):** Agreed. Analyzing MPA performance can be messy in this way.

3) Comment (R. van Woesik): I think variance is important. We actually compared the history of thermal stress and found it repeated itself. Historical regional hot spots seem to be true hot spots. It's only at the regional scale but is is a start.

4.) Question (S. Pannaman, Sierra Club): Do hot spots exist at deep ocean depths?
Answer (J. Bruno): I don't know. **(B. Detrick):** Natural variability is unknown to some degree. There is some reasonable data on temperature change below 2000 m. However, it is variable and influenced by ocean circulation.

5) Question (A. Chavez, NOVA): Taking into consideration that warming may be occurring at depth, how much do we know about the microbial community in deep sea corals?
Answer (M. Medina): There is major concern for deep corals in regards to how ocean acidification affects deep corals. pH impacts to deep coral communities are potentially greater, thus deep corals are more affected by acidification than shallow corals.

6) Question (R. van Woesik): What's the variance you are getting among those populations you are analyzing with a genomics approach?
Answer (M. Medina): We are just beginning to do more fine-scale work. There will be signals, but also random processes that add variance. When we first started these studies, the technology we have now was not available. As technology improves and more interest is generated in this area, we will be better able to answer those types of questions.

7) Comment (M. Hay): Margaret, you talked about ocean acidification and almost everyone is looking at physiology. I think the influence of pH and chemical detection on behavior might be a better emphasis. Fish are responding in non-physiological ways that aren't easy to predict yet have serious ecological consequences.
Answer (M. Miller): In the broader coral community, calcification is the obvious linkage. Yet, population level impacts including reproduction failure, quite possibly related to some degree to altered environmental cues, may be more important or at least needs more attention. **(M. Medina):**_There is a lot of interest in behavior and the microbiome. Microbial diversity can affect host behavior. Biofilms on crustose corraline algae (CCA) are altered when the CCA is exposed to thermal stress, and this has been shown to influence coral recruitment success. We are not looking closely enough at this. **(M. Miller):** More and more studies are investigating the sophistication of coral settlement. Cues and behavioral aspects of coral settlement are more

important than perhaps we have previously believed.

8) Question (E. Hodel, CSA International): Can Miller and Moore comment on where you see a potential management plan going? Given the large geographic scale under consideration, this seems to be a human issue.

Answer (J. Moore): This meeting is adding to the science base. A management plan is much further down the line and will only be created if it is determined that a species warrants listing. Regulating carbon emissions is not under the purview of NOAA. We could only identify that as an activity which is required for recovery. With regards to the two existing corals that are ESA listed (*Acropora palmata* and *Acropora cervicornis*) there are multiple things the statute allows us to do. We extended prohibitions to coral including take, sale, commercial activities, among others. Recovery plans are developed for each listed species that articulate specific threat abatement actions required for species recovery. The emphasis is also on protecting the ecosystem upon which the listed species rely. **(R. Aronson):** It is remarkable that this report from the BRT has climate change as the centerpiece as a threat to these corals. **(J. Bruno):** The EPA can come into play for regulating greenhouse gas emission.

Workshop completed.
