SUMMARY REPORT

NOAA Pacific Islands Corals Science Workshop
June 18, 2012

Local Lead: Dr. Michael Seki, Deputy Director, PIFSC
Chair: Dr. Robert Detrick, Assistant Administrator, NOAA OAR
Rapporteurs: Mariska Weijerman, Matt Dunlap, and Dr. Matthew Vandersande, PIFSC

Brief History

On October 20, 2009, the Center for Biological Diversity (CBD) petitioned the NOAA National Marine Fisheries Service (NMFS) to list 83 species of coral under the Endangered Species Act. On February 10, 2010 NMFS issued a 90-day finding that the petitioner's request may be warranted for 82 candidate species, 75 in the Indo-Pacific and 7 in the Western Atlantic. Directors of NMFS Pacific Islands Fisheries Science Center (PIFSC) and Southeast Fisheries Science Center (SEFSC) established a seven-member Biological Review Team (BRT) of scientists from five NOAA offices, National Park Service, and U.S. Geological Survey to assess the status of the 82 candidate coral species and estimate the risks of their extinction. On October 28, 2010 the BRT's Draft Status Review Report (SRR) was submitted to an external peer-review panel established by the Center for Independent Experts. The BRT addressed the panel's comments, completed the SRR and made it available to NOAA in September 2011 as the following document:

Brainard, R.E., C. Birkeland, C.M. Eakin, P. McElhany, M.W. Miller, M. Patterson, and G.A. Piniak. 2011. Status review report of 82 candidate coral species petitioned under the U.S. Endangered Species Act. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-27, 530 p. + 1 Appendix.

NOAA released the report to the public in April 2012 on the following NMFS website: (http://www.nmfs.noaa.gov/stories/2012/05/07_coral_documents_page.html).

The review of the status of the 82 coral species is a major undertaking because of the large number, and geographically dispersed nature, of coral species involved. Therefore, with the approval of a federal court, NMFS and CBD agreed to extend the deadline for issuing the 12-month finding on this petition to December 1, 2012. The extension afforded additional opportunity for the public to provide NMFS with information that may further inform the 12-month finding as to whether the petitioned action is or is not warranted. Two public listening sessions and two public scientific workshops were scheduled and held, one each in Hawaii and Florida, during which the evaluation process was explained and the public and experts had the opportunity to provide any additional relevant information on the matter (77 Fed. Reg. 30261-30262, May 22, 2012). Public listening sessions were also convened in Guam and Saipan.

This report is a summary[1] of the first science workshop, held on June 18, 2012 at the Keoni Auditorium, East West Center, University of Hawaii Campus, Honolulu, HI.

[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. Michael Seki (NOAA/PIFSC):

- The purpose of today's workshop is to discuss the science related to the 82 corals in the petition. A separate listening session will be held next week regarding the regulatory process.

Main points from Introduction by Dr. Robert Detrick (NOAA/OAR):

- Brief explanation of the purpose of the workshop: Open public meeting to discuss science behind, SRR and to accept public scientific input to assist the listing decision by NMFS.
- This workshop was organized at the request of Dr. Jane Lubchenco, NOAA Administrator. 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.
- The workshop will highlight the science of the 82 corals and has two thematic sessions. The first session concentrates on climate issues, and the second on ecology and adaptation of corals and reefs.
- Workshop participants can submit written comments either at the workshop or through the NOAA website.
- 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 report, but a verbatim transcript is not required and will not be made.

Main points from the presentation "Outline and overview of BRT results and conclusions" by Dr. Rusty Brainard (NOAA/PIFSC 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.
- The species question: "Is the candidate a species?" Corals exhibit morphological plasticity; coral taxonomy is based on morphology, but coral morphology (at the colony level and polyp level) can change based upon the environmental conditions of the habitat. Therefore, morphologically-based taxonomic descriptions may not be reliable or consistent. Genetic research is starting to discover that some species thought to be rare are not separate species, but are actually different morphotypes of the same species. Some genetic research on corals is also unveiling evidence for cryptic species. Dr. Zac Forsman will discuss more of this rapidly growing field of molecular systematics research in his presentation today.
- Threats: the evaluation of threats was divided into a ranking of negligible/low/medium/high. Threats needed to be assessed across the geographical range of the particular species. Specific threats were evaluated on all life 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. There is a relationship between warming and disease; (2) Disease; coral disease incidents have led to decreases in abundance and diversity, even highly managed areas such as the Great Barrier Reef have had decreases in coral cover due to disease outbreaks; and (3) Ocean Acidification; laboratory experiments are testing the effects of ocean acidification and finding solid evidence for reduced calcification by corals in acidified conditions, but this cannot be replicated under real world conditions so we still don't understand linkages.

- From the IPCC AR4 report, the BRT borrowed both the "foreseeable future" date of 2100 because of the relationship to climate model predictions, and the 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 Dr. Brainard's presentation:

1) What is the next step in the process, can additional information be submitted?

Answer: The status review report that was published in September 2011 won't be changed but additional scientific input will be considered by the NMFS Pacific Islands Regional Office (PIRO) and Southeast Regional Office (SERO) in arriving at the 12-month finding.

From Lance Smith (PIRO): All additional information that is submitted during the public comment period (up until July 31, 2012) will be considered in the decision-making process (a listing decision is due on or before December 1, 2012).

2) What adaptation studies were considered in the report?

Answer: We did explore that quite a bit; it is referenced in the report. We talked with subject matter experts and incorporated their input in the report. The report is a review document with 2100+ citations.

3) In the geologic record, there have been 5 major extinction events. Have those corals survived? Answer by Dr. Charles Birkeland: 20 Families of corals survived the cretaceous/tertiary extinction; it is the reefs that died out. In the Caribbean not all the families survived (see Dr. Birkeland's submitted narrative or the SRR for further information about the geologic record of corals). What is different from the previous mass extinctions is that presently change is much more rapid. Acidification is occurring on the order of decades, instead of millions of years. Dr. Mark Eakin: While families or genera survived those major extinction events, many species did go extinct.

4) What is the most useful thing to have comments on?

Answer by Dr. Robert Dietrick: Scientific information. Brainard: Any gaps filled on the life history stages, in particular the early life history and how the threats affect them.

Lance Smith: It is 82 different status reviews and decisions. We want as much species-specific information as possible. Normally a biological SRR has much more than 3 pages of information (which is the information given in the individual species accounts in the SRR).

Brainard: The climate modeling community is working on a review of the models for the next IPCC report (IPCC AR5, due to be released in 2013). If there is a big change in the predictions by the models, it may change the assessment in the corals report.

Thematic Session 1: "Climate Change in the Pacific and Climate Impacts on Coral Reef Ecosystems"

Main points from the presentation "Summary of biological status review of climate change risks to corals" by Dr. Mark Eakin (NOAA Coral Reef Watch and BRT member):

- Summary of parts of the global threat section (Chapter 3) of the SRR: (1) Already seeing large scale bleaching; (2) the threat of acidification has not been easy to measure in the field, but many laboratory studies indicate a negative effect on coral growth with increased acidification; (3) sea level rise is not a major threat for extinction relative to other global threats because the scale of its impact is limited; (4) there is natural variability of CO_2 in association with glaciations but we are already outside of this natural variation; anthropogenic CO_2 is accelerating and tracking the worst case scenario of model outcomes.
- Update of CO_2 in atmosphere: There was a strong dip in CO_2 emissions with the 2008 global economic downturn. The curve has since turned upward and is now approaching the worst case scenario line from the 2007 AR4 projections (although the curve is much steeper now since the line is coming from the bottom of the dip created by the global recession). There are two drivers: (1) Human population growth, at the current rate we will have doubled the population in the next century; (2) human consumption, per capita emissions are increasing because of individual consumption.
- Updated summaries of bleaching incidents from Reefs at Risks Revisited (2011): While this publication came out after the first draft of the SRR, the BRT did consider this additional information in the latter stages of preparation of the SRR. There is no evidence of global coral bleaching pre-1982 but now 40% of the world's reefs have been affected by bleaching. Models of bleaching with current rates of "business as usual", i.e. a continuation of the current rates of fossil fuel burning and carbon dioxide production, predict the NOAA Coral Reef Watch's Bleaching Alert Level 2 will increase at least 10%. Ocean temperatures around reefs are likely to rise 0.8°C by 2030s, 2.8°C by 2100, increasing bleaching frequency and intensity. There has been low recovery in the Caribbean following bleaching events.
- Other impacts of warming: We often don't see the bleaching of coral embryos but we can assume it occurs.
- In the SRR, there is a table summarizing coral studies on impacts of acidification. Rising CO_2 reduces carbonate concentrations and pH. Some coral species do okay at these elevated CO_2 concentrations, but these are not the species that are petitioned.
- We don't know how changing storm tracks will affect coral. This may end up being a larger threat than predicted.
- Sea level rise is not expected to be a major threat for extinction.

Questions from the audience following Dr. Eakin presentation:

1) A questioner referenced the West Pacific Warm Pool discussed in an article by Kleypas et al. (Kleypas et al. 2008, Geophysical Research Letters). He didn't see this paper addressed in the SRR. The theory in the article is that this particular Western Pacific Warm Pool is not likely to get much warmer, even with continued global warming and that this natural ocean thermostat may protect some coral reefs. The implication of the article was that this area of the ocean is already as warm as it will get, and may therefore serve as a functional reserve for corals.

Answer: Eakin: The paper and the model were considered by the BRT. The paper is contentious because of criticism in the scientific community about whether the model can accurately determine whether or not the region will continue to warm. A rebuttal was quickly published challenging the model in the Kleypas paper.

Main points from the presentation "Ocean acidification effects on corals and their extinction risks" by Dr. Anne Cohen (Woods Hole Oceanographic Institution):

- Overview of calcification mechanisms by calcifying organisms: Modern reefs are products of $CaCO_3$ production of reef calcifiers: reef building corals, coralline algae, etc. Coral calcium carbonate production is 1000x higher than the inorganic process. Major reef eroders are worms, parrotfish, sea urchins, and sponges, which drive the process of dissolution. This cycle is tightly balanced, with production slightly higher than erosion and dissolution.
- Overview of mechanisms for absorption of CO_2 into the ocean: $CO_2 + H_2O + CO_3^{2-}$----> 2 HCO_3^{-}. Decreases in $C0_3^{2-}$ concentrations and increases in HCO_3^{-} concentrations result in more acidic conditions (i.e., lower pH). Ocean acidification involves the increase in absorption of CO_2 in seawater, resulting in higher bicarbonate ion concentration and lower carbonate ion concentration. CO_2 increase was 3% per year over the last decade.
- How do we know ocean acidification is affecting reefs? CO_2 manipulation experiments in the lab (e.g., Cohen 2009: at the predicted carbonate ion concentration of 2100, corals can't generate and the form of crystals also changes); it comes down to physical chemistry. Bioerosion increases under elevated CO_2, this means that at some point the reefs will go from net accreting structures to dissolving structures.
- Are some species more sensitive than others? Very few researchers have studied this. Cohen (2011) found some gender difference in sensitivity: spawning female corals are more sensitive to acidification than male corals and non-spawning females. Preliminary in situ studies indicate that reefs may be more sensitive than species; i.e. the same species may have a different susceptibility to acidification on different reefs.
- Carbonate system chemistry of reef systems is variable in space and time. Diurnal variation is the source of the largest variability. Establishing baselines from which to monitor change on specific reefs is a challenge.
- Another process that affects calcification rates is the aragonite saturation state. Some reefs can calcify rapidly in water with low aragonite saturation states. The Kaneohe Bay barrier reef is an example.
- The more tissue a coral has, the more surface area it has to bind calcium and carbonate, and the better the coral can continue to calcify in more acidic environments. The availability of nutrients also plays a large part in the corals ability to withstand deleterious effects of acidification. Some oceanographic models predict less upwelling and lower surface ocean nitrate concentrations with warming, exacerbating the negative effects of ocean acidification.

Questions from the audience following Cohen presentation:

1) In a recent study was there some evidence of corals switching from carbonate to bicarbonate calcification in an acidified environment?
Answer: Not sure which study is referred to, but such switching would likely have something to do with nutrition.

Main points from the presentation "Regional climate change projections for the insular central and western Pacific" by Dr. Kevin Hamilton (IPRC):

- Average temperature has increased dramatically over last half century, with intensification at high latitudes and more variability in air temperature over the ocean at lower latitudes.
- Model results have been derived from 22 different models. The model results are similar in some ways, but quite different in other respects, with very high variability overall.
- Comparison of CMIP5 (Coupled Model Intercomparison Project Phase 5, 2011) and IPCC AR5 (Intergovernmental Panel on Climate Change Fifth Assessment Report, expected in 2013).
- Focus on models for Hawaii sea surface temperature (SST) and wind speed. CMIP models have improved over the last few years, but there is very little agreement between predictions, with up to 4 degree differences in predicted SST. More winds result in more wave action which will lead to more coral erosion.
- Rainfall in Hawaii tied to oscillations such as the Pacific Decadal Oscillation.

Questions from the audience following Hamilton presentation:

1) Regarding the differences between the global climate models and their predictions, could you clarify the effects of down-scaling the models to focus on this region, and is this limited by the boundary conditions of the global models?

Answer: As discussed in my presentation, not all of the predictions of the global models agree. These differences, and the issue of boundary conditions, were taken into consideration for the regional model.

Main points from the presentation "Potential threats of climate change and coral disease on coral reef resistance and resilience" by Dr. Greta Aeby (HIMB):

- Disease is normal in all animals, including corals. Disease has been reported much more frequently since 1985 partly because more scientists are looking for it; however, studies have shown growing disease occurrence in the Florida Keys and the whole western Atlantic. In the Pacific, we are seeing similar patterns, an increase in the number of cases and the extent of disease.
- Disease can be caused through biotic transmitters or through abiotic conditions.
- There are different types of disease (e.g., tissue loss, discoloration, growth anomaly) and different levels of virulence (e.g., high virulence of the acute *Montipora* White Syndrome that killed a coral colony in 10 days).
- There is differential susceptibility among coral genera. The 3 most susceptible genera in Hawaii are *Montipora*, *Acropora*, and *Porites*. See Aeby's narrative for a table listing the 3 coral genera with the highest disease prevalence in various regions (Great Barrier Reef, American Samoa, Micronesia, etc.).
- Recently, more information has become available on the etiology of the different diseases, the importance of host abundance, thermal stress (i.e., high or low abnormal temperatures), and human stressors.

Questions from the audience following Aeby presentation:

1) It is unclear why more of Aeby's disease work wasn't included in SSR. Can you explain why?

Answer: I reviewed the SRR after its completion and included new information in my presentation (in my slides and narrative). The lumped disease was reported as a high threat in the SRR, which is justified. Disease has been devastating to Caribbean coral populations. While disease prevalence is lower in the Pacific than the Caribbean, it does appear to be increasing in the Pacific.

2) Where do the diseases come from?
Answer: Modes of transmission are through direct contact with an infected coral, through the water column, and via a host; similar to disease vectors in humans. One common factor in disease infection is the presence of another stressor (i.e., a compromised host). Bacterial pathogens are common.

3) How about the issue of bacterium switching?
Answer: It has been poorly investigated so far. There is an example from the Florida Keys, but it is likely occurring elsewhere. In Kaneohe Bay, sewage spills are a biological stressor. Etiologies of bacterial infections are becoming more known.

Public input with roundtable discussion from Drs. Eakin, Cohen, Hamilton, and Aeby

There were no registered speakers.

Questions from the audience:

1) Would listing of coral species and the subsequent federal protection help corals cope with the disease? Has the listing of the two Caribbean *Acropora* species resulted in an improved survival rate or reduced spread of disease?
Answer by Aeby: By the time *Acropora cervicornis* and *Acropora palmata* were listed, their population density was already very low. Prior to listing, the coral cover of those two species had already declined substantially. However, if listing can reduce stressors for the Pacific it could help the candidate species.

2) If the more sensitive corals are wiped out and we are left with the more robust ones, can they cope with disease?
Answer by Aeby: Host pathogen evolution shows that diseases want the host not to die so it can pass onto the next host. For diseases that are transmitted through vectors, that is not true, so the mode of transmission is important.

3) A questioner remarked that Anne Cohen described a classic dose-response mechanism for a coral's response to ocean acidification. Is there such a dose-response mechanism in the models for a coral's predicted response to ocean warming? How did the BRT consider the expected response by corals under different levels of warming? For horizontal and vertical response?
Answer by Eakin: Thermal stress is evaluated over long periods. For example, NOAA's degree heating weeks (DHW) methodology looks at thermal stress of 12 weeks to get a reef perspective overview. However, you get very different responses to thermal stress at the coral species level so this is not available for individual species. The slow growing species that are less susceptible to bleaching may be more vulnerable to acidification. When growth is a factor this is especially important. The BRT took the generalities of thermal stress and then interpolated them to the species level. In estimating the extinction risk the BRT took into account the coral's present habitat types, depth range, and the geographic distribution of the corals. There may be a refuge at depth for some coral species, but temperature anomalies could also affect deeper habitats. For example, the Flower Garden Banks (where the shallowest bank is 20-m deep) recently had bleaching corals. Mesophotic corals may behave differently than shallow corals. The anomaly is the important factor, not the temperature. The predicted warming range for ocean temperature by 2100 is one to three degrees, but even the lowest value of one degree is still twice what we have seen so far, with resulting widespread bleaching and disease, so it will likely have major impacts. Geographic distribution is another factor the BRT took into account in

estimating the extinction risk. For example, a species limited to the eastern tropical Pacific with high variability is more susceptible to thermal stress than a species with a wide geographic distribution.

4) What do you think about the recent (2011) Dubinsky et al. review book (Coral Reefs: An Ecosystem in Transition) with a chapter by Barbara Brown that questions the accuracy of reports on bleaching and concludes that there has been no rigorous evaluation of regional differences?
Answer by Eakin: The incidence of bleaching is compiled in a database by Reef Base, however, there are numerous data quality issues. These issues are being addressed and remedied. Despite some issues with data quality, Reef Base bleaching reports tend to track and agree with the severity of thermal stress events from satellite data. Remember, back in 1983 the internet was just beginning, but now reporting is better. Long-term consistent reporting sites are now present.

5) Further group discussion in the room about the Kleypas et al. paper and the findings of relatively slower sea-surface warming in the warm pool.
Comment by Eakin: The size of the warm pool will likely get larger. The warming will likely be slower within the warm pool, but you still get warming. In the Coral Triangle (CT), the edge of the warm pool is matching global increases. The rate of change of pH and CO_3 is lower in the CT than in the Caribbean. A rebuttal to the Kleypas paper has been published since then, challenging her model.

6) Nutrient availability will affect response; more food will help corals be more resilient to cope with warming?
Answer by Cohen: At equatorial reef sites, increased upwelling is predicted by global climate models. So, these reefs could receive some mitigation effects from thermal stress as they receive more nutrients. However, deeper waters have a lower pH. It is the combination of different stressors that we don't know a lot about and make it difficult to predict what is going to happen (new paper by Cohen published in July on this topic).

7) How are acidification experiments run?
Answer by Cohen: Early lab studies added acid to tanks to test the effects on corals, but this also lowered inorganic carbon available to corals so results were not conclusive. Now, tanks get bubbled with CO_2 to better replicate what happens in the real world. The coral response was similar suggesting that corals care about the carbonate ion concentration and not the bicarbonate ion concentration.

8) How might the range of corals and zooxanthellae change with warming and acidification?
Answer by Eakin: Publications on the range of nutrients, sediments, and light indicate that there is an increase in zooxanthellae per cell when light is low. As one moves poleward, the angle of the light changes, which also has an influence on corals. Light influences coral growth, and temperature and acidification work together: colder water absorbs more atmospheric CO_2 and is, therefore, more acidic, some coral (weedy species) will expand rapidly. Going poleward you will see more corals but not necessarily reef growth.

9) Is caution needed in inferring that upwelling will increase calcification rates of corals? Might the additional nutrients due to upwelling not benefit corals as other marine biota grow much more rapidly?
Answer by Cohen: We did see more coral calcification in areas of natural upwelling, but yes, you do need a healthy community of herbivores to keep other biota in check.
Richmond indicated very low recruitment of corals onto settlement plates in upwelling regions of Panama.

Birkeland: Nutrient inputs from fertilizers are so much greater now, resulting in increase in the phytoplankton and dead zones in oceans.
Cohen: Nutrients benefit corals up to a point, by allowing them to continue to calcify in acidified environments, but eutrophication eventually favors algal growth over coral growth.

10) Is reef production (larval recruitment) hindered by algal growth in high nutrient area? Would you expects colony growth versus reef accretion?
Answer by Cohen: We need to know more about upwelling regions. Competition for real estate is a big problem, so if they don't take hold, they can't grow even in favorable conditions. Sometimes coral grow slowly in fast growing regions.
Eakin: For example, *Pocillopora elegans* was ranked twice in the SSR partially due to the different reproductive strategies in the Eastern Pacific vs. Western Pacific (broadcast spawner and brooder).

11) Sea level rise was ranked low in the SSR, but would it be ranked higher if the predictions are changed to higher levels?
Answer Hamilton: More recent work suggests that sea level rise will be more substantial than the AR4 prediction.
Eakin: In the SRR report we considered a sea level rise of between 1 and 2 m and I don't think that the new ARP5 report will have a different number. This time we look at high sea level rise and ocean acidification and they are working against each other. With increases in sea level rise and coastal erosion, land-based sources of pollution (LBSP) will increase as well. For example, consider how many gas stations are located on the coast within the zone of a 1-m sea level rise. These properties will be inundated and even if the facilities are removed ahead of time, the contaminants in the soil would move into the marine environment over time. So, we did consider all these aspect but we still think that the effects would be of less importance than the other stressors.
Cohen: With sea level rise, the drag (i.e., friction of water over the reef) will change as well. High drag is known to increase calcification rates on reefs. The effects of changing sea level and drag are not well understood.

12) How can you defend against climate skeptics? What do you say to those who have no faith in the IPCC reports?
Answer by Hamilton: One response is to ask for alternative explanations for the warming we have seen and measured. Skeptics haven't been able to explain the climate changes. The best-informed skeptics hone in on the uncertainty brought in by our relative inability to model the effects of clouds as climate changes occur. However, IPCC 2007 report said they were 90% sure that humans have caused climate change, and 99% sure that future climate change will be caused by anthropogenic inputs.
Eakin: Skeptics are good to keep modelers and scientists on their toes and, therefore, valuable and necessary. However, the deniers are not basing their conclusions on science and have made up their mind and, therefore, are more difficult to convince.

13) How do we interpret study results of acidification experiments without a solid baseline? What is the 'average' saturation state? How can we predict changes?
Answer by Cohen: On a majority of the reefs the values are lower than in the open ocean so an exact number of the global aragonite saturation is very difficult to estimate. We take the values that we measure and impose change that would be predicted by the models for reef areas that are most sensitive (e.g., back reefs will see undersaturation sooner).
Eakin: Carbonate saturation state varies very much from reef to reef which complicates global predictions.

14) Are recent disease observations influenced by thermal stress in the Indo-Pacific?
Answer by Aeby: New tissue loss disease (e.g., white viral pathogen tissue loss in the Red Sea) is related to temperature and we also know that some bacterial disease types are temperature sensitive. We need more information.

Thematic Session 2: "Coral Reef Ecology and Adaptation"

Main points from the presentation "Summary of biological status review of risks to corals and coral ecosystems" by Dr. Charles Birkeland (University of Hawaii and BRT member):

- Dr. Birkeland summarized how corals differ from other species for which risk is evaluated under the ESA. Specifically, corals are a foundation species (i.e., they create the foundation for an ecosystem that allows for the presence of many other species). Unlike birds or fish, corals are not mobile as adults, they are sessile. The transport of coral larvae determine where the species will live and their distribution is affected by water currents. Most corals have very large geographic ranges.
- Allee effects (reduced individual fitness as a species becomes rare, causing even more rarity) are thought to occur in corals.
- Dr. Birkeland explained the allee effect on fertilization, fecundity, dispersion, connectivity, and predation of corals.

Questions from the audience following Birkeland presentation:
None.

Main points from the presentation "Climate change and coral reefs, an integrated perspective" by Dr. Robert Richmond (University of Hawaii):

- According to the Global Coral Reef Monitoring Report, 30% of coral reefs are destroyed or negatively affected by human activities. Extinction risk is on a spatial and temporal scale. We need to separate acute from chronic effects and natural from anthropogenic impacts.
- Global climate change has led to massive regional bleaching events, alternate stable states, and ocean acidification. It could lead to a reduction in diversity resulting in a situation similar to the 'Irish potato famine' of reefs (i.e., Irish raised one single variety of potato that grew well in the region – loss of diversity – these were wiped out by a pathogen).
- Diversity usually means species, but we need to consider population genetic diversity. Differential susceptibility to stressors happens as a result of genetic diversity (e.g., differential mortality and recovery to bleaching events in Palau).
- Dr. Richmond described acidification experiments by Fine and Tchernov (2007): 450 ppm is the CO_2 break point for coral reefs. Coral physiological adaptations include changes to growth rates; reproduction but no reef building. High acidification treatments in the Fine and Tchernov experiments created 'naked' polyps in aquarium studies — coral polyps survived but their carbonate skeletons dissolved – the corals could re-calcify after a return to normal levels of acidification. However, unprotected coral polyps do not survive for long on a coral reef.
- In Hawaii, sediment plumes that used to be localized are now regional, thus impacting large swaths of reefs. Heavy rain events turn the water brown around entire islands, not just localized areas such as valleys or rivers.
- Mortality is the indicator we currently use; it is a poor indicator because it is too late. Use (1) protein production in corals to diagnose certain stressors; as temperatures elevate, the proteins begin to

denature; (2) changes in community structure; symbiotic crabs and shrimp protect corals they live with, but after bleaching, these symbionts leave and predators, such as, crown of thorns seastars, can attack.

- Future scenarios for coral reefs. Given the current trajectories of declining coral cover, we can buy time, or a delay, by reducing local pollution and other stressors, and then tackle global climate change.

Questions from the audience following Richmond presentation:
None.

Main points from the presentation "Current issues of coral species systematics; hybridization, phenotypic plasticity, and cryptic biodiversity" by Dr. Zac Forsman (University of Hawaii):

- Description of coral molecular systematics and understanding species boundaries
- Species definitions vary. There are over 24 varieties of species definitions in the scientific literature. From the Endangered Species Act: "the term species includes any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which **interbreeds** when mature." Interbreeding is key, as defined by Ernest Mayr's biological species concept.
- Veron proposed reticulate evolution by sea surface vicariance.
- Coral taxonomic view is based on morphology at both the corallite level and colony level.
- Polyphyletic means morphological groups don't match with genetic groups. Where do you draw the line with continuous gene flow? Convergent evolution occurs when different species evolve separately, but arrive at a similar-looking conclusion, i.e. having very similar phenotypic traits.
- Corals have pervasive polyphyly at the family, order, and genus level.
- It's very difficult to separate differences at species level of hybridization, polymorphism, and plasticity. Peter Todd (2008) gives an excellent review of these types of studies.
- *Montipora dilitata* experiments to determine if it is an ecomorph.
- Conclusions – Colony-level morphology more variable than previously thought. Why so variable? (1) phenotypic variation (population level), and (2) incipient speciation (sympatry). Surprises: What was thought to be rare might not be, and what seems to be common may hide rare cryptic species.

Questions from the audience following Forsman presentation:

1) If multiple species look the same, what is a field biologist to do?

Answer: It is not the same case for every coral. Genetic work may help to pick out those characteristics. Maybe we can pick out characteristics to identify species in the field.

2) How should regulators deal with the taxonomic issues?

Answer: We don't have the tools to solve all of these issues. A reproductive trial may help. Maybe we need to address a species as if it were reproductively isolated.

3) Kaneohe Bay is relatively young. Are there corals which have been known to speciate recently? Could *Montipora dilitata* in Kaneohe Bay be a true species, but too young to be detected by the molecular markers currently available?

Answer: It is difficult to detect recent speciation. You need to look at gene frequency to study gene flow and we need to conduct reproductive studies to learn more.

4) Question about using mitochondrial markers to detect recent speciation.

Answer: Potentially yes, but the field is relatively new and the number of markers available is limited. Many gene rearrangements make it difficult to compare different species that don't have the same marker.

Public input with roundtable discussion from Drs. Birkeland, Richmond, and Forsman:

There were no registered speakers.

Questions from the audience:

1) Adaptation of *Acropora* coral to stressors reported in recent papers though new combinations of zooxanthellae– any thoughts on these capabilities?
Answer by Richmond: There is some evidence for that in some situations, but it is not well known how widespread or effective this adaptation will be. The Nature Conservancy reports from Palau show that the marginal reefs appear to be the most resilient, however, climate models showed that the whole of Palau was in the 'red zone.' From a management perspective it is difficult to decide what reefs to 'save.' Adaptation works only if you have sufficient time, and it seems that the present changes are too quick. Severity and timing of the threat events has as much influence on whether adaptation will be effective for corals to survive, as do the corals ability to adapt.
Forsman: Some strains of zooxanthellae are very host-specific, so the adaptive bleaching hypothesis might not work for all species.
Eakin: Few studies have looked at what happened during the succession after a thermal stress on a long-term basis — the one that did showed that indeed corals have a different clade of zooxanthellae directly after the stress but a year later they had the same zooxanthellae and were just as vulnerable.

2) Unlike succession of a forest after fire, we don't understand reef succession?
Answer: Succession does occur, but without bigger old corals you lose big reproducers; small corals don't reproduce as much. Succession in corals is not that clear.

3) Is transplanting corals a useful approach for restoration efforts?
Answer by Birkeland: Perhaps, but it is better to solve the problem than to treat the symptom. Transplantation is very costly and if you don't solve the original issue that is driving excessive coral mortality (e.g., sedimentation, poor water quality, predation, physical damage, etc), restoration may not work for long. For very rare species that are already functionally extinct because of the large space between them, transplanting is necessary.
Richmond: Reducing the threat is the most important. If you have corals of opportunity, such as from a harbor dredging, then it may be useful to increase the success of a restoration site by using these corals. So, if you have enough resources, transplanting is an option.
Birkeland: How do rare species (e.g., *Dendrogyra*) successfully reproduce? For example, land plants successfully reproduce sexually because they have pollinators. There might be a mechanism that we still don't know about with corals.

4) To what extent does the reported extinction risk depend on the perceived lower depth limit? How accurate are the present depth ranges for some corals when they seem to coincide with the SCUBA depth limit?

Answer by Richmond: recent work has shown extensive reefs at mesophotic depths. These studies also show that land-based sources of pollution have a significant effect on these corals because they already live on the edge of survival (i.e., low light conditions).
Forsman: The deep refugia hypothesis is a popular theory but might not work over ecological time scales as their zooxanthellae community differ.
Brainard: We did discuss the depth range extensively in the SRR.
Tony Montgomery (USFWS, deep reef diver): For some species we do find range extension but in general the mesophotic reefs are totally different than the shallow reefs, with patchy incidences of corals rather than large expanses of corals (he is referring only to his deep encounters of coral species that have ranges supposedly limited to shallower depths. They have documented large expanses of reefs with corals known to be at mesophotic depths, e.g., *Leptoseris* spp.).

5) The Endangered Species Act requires consideration of the full extent of the species' range, yet for some corals, the scientists admit we don't have complete information about their range – either by region, or by depth?
Answer by Forsman: We make a map to the best of our abilities. Unfortunately, it is not as good as it should be. Reproductive testing is expensive and underfunded. Haplotype differentiation will take more work.

6) Reproduction of genets (i.e., a clonal colony) is complicated. In one instance, one reef had three different genets but each spawned at slightly different times (Margaret Miller research)?
Answer by Eakin: This complicates restoration potential, especially with transplantation mitigation, as it is very difficult to recreate that synchrony.

Workshop completed.