Executive Summary

NOAA's Coral Reef Watch and the University of Queensland conducted a workshop in Queensland, Australia (February 2010) to investigate additional ways satellites can be used for monitoring coral reef vulnerability in a changing climate. Over the course of a week remote sensing scientists, coral reef researchers, and resource managers from around the world discussed "state of the art" uses of remote sensing satellites for coral reef monitoring as they relate to climate change impacts on coral reefs. This Technical Report documents the presentations and discussions held during the workshop and mentions future directions that will benefit this community.

The priorities of the workshop were to:

1) Explain how climate change is affecting coral reefs.
2) Discuss mitigation strategies for safeguarding coral reefs.
3) Investigate how current coral reef remote sensing products could be improved.
4) Explore new remote sensing products of use to coral reef managers and researchers.
5) Identify additional technologies of use to the coral reef remote sensing community.

Focal presentations and discussions of the workshop are listed below.

- Numerous strategies for protecting coral reefs from the effects of climate change were discussed, one of which is the switching of zooxanthellae from thermally resistant coral species to less thermally tolerant coral species. The prospect of this was raised in three of the workshop presentations (Hoegh-Guldberg, Berkelmans, and Dove). The general consensus from these presentations is that coral's ability to switch among *Symbiodinium* clades is unlikely to safeguard coral reefs against the multiple effects of climate change. Presenters noted several caveats with this approach such as the limited duration wherein many host coral can accept foreign zooxanthellae (Berkelmans), the lengthy amount of time necessary for corals to evolve and become thermally tolerant (Hoegh-Guldberg) and the potential health deficiencies associated with transferring unfamiliar zooxanthellae to coral (Dove). These biological hurdles suggest that this technique of protecting coral from climate change would largely be ineffective and a waste of resources.

- Coral reef ecosystems are linked with other tropical marine ecosystems, which include seagrass meadows and mangroves. Research indicates mangroves and seagrass meadows provide vital ecosystem services for coral reefs that include shaded areas for small colonies of corals, reef fish nurseries, filtration of coastal surface runoff, feeding areas for sea turtles, and early warning areas for coastal environmental stressors. Therefore, workshop participants voiced an interest in monitoring changes to tropical marine ecosystems associated with coral reefs, especially seagrass beds (Enríquez), using remote sensing tools. Much of the technology to derive this information is currently under development and could be used to derive important information about how seagrasses are affected by light (Skirving and Enríquez). There is also interest in seagrass cover but higher resolution data are needed for accurate estimates of this parameter.

- Sedimentation and excessive algal growth on coral reefs, which is caused by high amounts of terrigenous runoff and inputs of nutrients, can negatively impact coral

health. Recent studies have even suggested that some coral reefs can increase their bleaching tolerance if nutrient runoff is decreased (Wooldridge). Ocean color remote sensing data are helpful for determining these water quality parameters in optically deep areas but require additional research and advancements for coral reef use in coastal areas. In two presentations researchers outlined the efforts being taken to advance ocean color technology in order to obtain accurate retrievals of water quality parameters in areas over coral reefs. One project between NASA and researchers at the University of Queensland is looking into developing algorithms to determine water quality parameters over coral reefs and incorporate this into the NASA ocean color image analysis software, SeaDAS (Weeks). Other ideas and initiatives for the advancement of ocean color technology include efforts on the part of CSIRO to develop compliance products for water quality total maximum daily loads (Dekker). While technological advancements are needed, there are a number of products that ocean color data can provide.

- An exciting development discussed during the workshop was the transition from 50 kilometer to 4-kilometer operational products and climatologies (Eakin). While the spatial resolution of CRW products is improving, and there is excitement about the improved spatial resolution, there is still a desire among researchers for higher spatial and spectral resolution for coral reef monitoring applications (Fearns). Many of the questions researchers and mangers have are at small scales and this finer resolution would facilitate answers to these. Currently most of the data at these requested higher resolutions are cost prohibitive and not compatible for operational, near-real-time products.

- Information Technology (IT) methods, such as machine learning (the branch of artificial intelligence that uses computer algorithms to facilitate the learning/evolution of computers based on data the computer analyzes) and data sharing networks, have the potential to advance coral reef research and coral reef remote sensing products. The use of machine learning to automate procedures associated with the processing and manipulation of remote sensing data has great potential (Ciesielski). Machine learning technology has the capability to discern between contrasting patterns and colors but subtle differences are more difficult to differentiate. Advancements in data sharing networks are also making data easier to collect and store for researchers. A couple studies are enhancing the quality and collection of citizen science data and compiling coral reef data from multiple research entities into singular data sharing networks to advance the study of coral reefs (Hunter).

- Coral reef remote sensing products legitimate resource manager decisions in the eyes of stakeholders. The importance of validating management decisions using data and third party resources is integral to maintaining stakeholder trust. In the absence of this data many decisions are reduced to bilateral debates that are not easily resolved. While some events, such as bleaching events, may not be readily apparent to some stakeholders, when equipped with remote sensing products it is easier for managers to convey the rationale for their management decisions (Causey and Kosaki).

- Coral reef resource managers agreed that it is more beneficial to have a remote sensing product that has known limitations than to have no product at all (Causey and Kosaki). Remote sensing products may work well in one part of the world and not in another due

to a variety of complications such as platform technical limitations or algorithm inaccuracies. Many remote sensing scientists are aware of these problems but the end-user may not be. These limitations should be conveyed to the resource manager so end users are aware of this aspect when making their management decisions and when answering stakeholder questions.

- Future coral reef remote sensing products will ideally incorporate algorithms that include multiple parameters such as temperature, light, pH, wind, seasonality, sediments and nutrients. Currently many of these parameters are being collected as individual, operational, or experimental products. Many remote sensing scientists and coral reef researchers at this meeting would find value in combining these into a singular coral health product. While there are still inaccuracies to sort out with existing products and developments are needed for experimental products, this is an interesting multidisciplinary and applied focus to have for a future product.

This workshop facilitated the exchange of ideas necessary for the enhancement and development of more applicable and rigorous remote sensing tools for monitoring coral reefs. Information derived from this workshop and documented in this report will provide remote sensing and coral reef scientists with information and ideas for future products that will be beneficial to coral reef managers, scientists, and policy advocates.