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PROJECT 4: SEA SURFACE TEMPERATURE MONITORING ACROSS THE BIRD'S HEAD SEASCAPE (CONSERVATION INTERNATIONAL)

BACKGROUND

Sea Surface Temperature (SST) is one of the primary oceanographic factors controlling the development and growth of coral reefs. Significant variances in SST (such as those predicted as a consequence of global climate change) are known to cause significant stress, coral bleaching, and even mass mortality in reef corals.

Recent theoretical advances in the design of MPA networks have stressed the importance of identifying and prioritizing the protection of those reefs that show natural *resilience* to global climate change as a result of either cold-water upwelling, shading, or "pre-adaptation" to warmer temperatures or significant variations in SSTs. Recent studies have shown that corals subject to different temperature regimes frequently have different clades of algal zooxanthellae (*Symbiodinium sp.*) that show different temperature tolerances. Corals that are normally subject to warm waters frequently harbor heat-tolerant zooxanthellae that may be the key to the recovery of surrounding corals that might bleach during high-temperature events (see Appendix 4.1.1 for details of this mechanism).

Although remote-sensing technology provides real-time SST data on a global scale, the resolution of these data is frequently not fine enough to reveal the very significant variations in SSTs to which corals might be exposed, even over a transect of only 500 meters. In Phase I of the BHS EBM project, 62 TidBit temperature loggers were installed across the BHS (from Cenderawasih Bay to Triton Bay) in a variety of oceanographic settings in order to record SST variation accurately on a fine scale. Results of this monitoring to date reveal that reefs in Raja Ampat experience high temperature variations (up to 15° C) over weeks and months, while reefs in Cenderawasih Bay, Jamursba Medi, and Triton Bay are subject to a much more stable temperature regime, with only 5° C variance over a year.

By continuing this SST monitoring, we can measure long-term trends in the SST pattern as well as the impact of El Niño and La Niña events, which have been associated with mass coral bleaching, on SST in the BHS. In addition, we plan to transfer the dataset and monitoring program to the State University of Papua in Manokwari (UNIPA) as a capacity-building initiative.

Having identified the areas with frequent cold-water upwellings as well as those with frequent warming events, we were then able to identify reefs that may be less likely to bleach and die due to climate change. Subsequently, we assisted the governments of the Bird's Head Seascape in planning a network of robust MPAs that can ensure the long-term sustainability of coral reefs and the fisheries and tourism that depend on them.

GOALS AND OUTPUTS

The objective of the study was to identify not only the full range of temperatures to which corals in the BHS are exposed, but also to (1) reveal important areas of cold-water upwellings, which are important both for fisheries and for identifying reefs that are resilient to global warming and (2) identify areas that are normally subject to very warm waters and might have corals and fishes that are "pre-adapted" to tolerate higher temperatures resulting from global climate change.

The sites where the TidBit temperature loggers were placed represented the broadest possible range of temperature conditions to which live corals in the Bird's Head might be exposed — including intertidal reef flats, deep reefs subject to frequent cold-water upwellings, enclosed shallow bays and lagoons with limited water circulation, and "normal" fringing reefs, atolls, and seamounts throughout the seascape. Loggers were placed only in areas with surrounding live coral growth.

A total of 78 temperature loggers were installed — 51 in Raja Ampat and Jamursbamedi, 21 in the Biak-Cendrawasih Bay area, and six in the Kaimana-Triton Bay area (see the map in Appendix 4.1.2) — at depths of one, three, 20, or 40 meters. The loggers, which recorded temperatures every 15 minutes, were recovered every six to 12 months for downloading and reinstallation.

Of the 67 loggers installed since July 2005, 60 have provided long-term data series (summarized in Appendices 4.1.3, 4.1.4, and 4.1.5). The other seven logger sites have experienced repeated "predation" events — thefts — though replacement loggers have been placed in each of these areas. Appendix 4.1.3 provides summary data and graphs from the 51 loggers installed in Raja Ampat and Jamursba Medi.

The Raja Ampat loggers revealed an overall average temperature of 29.12° C over the past 2.5 years. They have also recorded an incredible range of temperatures (21.25 to 35.74° C) to which Raja Ampat corals have been exposed. These values have less variation (less cooling but also less warming) compared to the previous sampling periods (avg = 29.02° C; min = 19.33° C; max = 36.04° C).

By comparison, the loggers in Jamursbamedi recorded average temperatures of 29.3° C, with a narrow range of only 27.6 to 30.2° C. A closer look at the individual site results from Raja Ampat revealed several important areas of cold-water upwellings, including Southeast Misool and the Dampier Straits, Sagewin Strait, and the Bougainville Strait in NW Raja Ampat. These cold upwellings may be seen all year but are typically most intense during the southeast monsoon period from June through September, when strong winds from the south help drive them.

Appendix 4.1.4 summarizes the temperature time-series data from four loggers in the Kaimana-Triton Bay region. These loggers, which were installed only in April 2006, have revealed that this region is on average significantly colder than Raja Ampat (where the average temperature is 28.12°C), with a recorded range of 22.28 to 30.94° C. A strong seasonality of temperature fluctuations was documented, with cold-water upwellings most prominent during the southeast monsoon period of June through September. In the Phase II BHS EBM Program, the number of loggers installed in this important region was increased in order to develop a better understanding of the temperature regime there.

Appendix 4.1.5 summarizes the temperature data collected from sixteen loggers in the Biak, Manokwari, and Cendrawasih Bay region. Compared to Raja Ampat and Kaimana, this region showed a temperature regime with a narrower range of adaptability to change. Loggers revealed an average temperature of 29.6° C with a recorded range of 24.94 to 31.56° C. Even this range is misleading as it is the result of a few abnormal cold and warm readings. On average, all 16 loggers showed that the temperatures stayed narrowly between 28.5 and 30.5° C for most of the year. This finding, combined with data from the genetic connectivity study that revealed that Cendrawasih Bay has limited connectivity with the rest of the Bird's Head Seascape, suggests that Cendrawasih should indeed be viewed as a special management area within the seascape. Our findings suggest that Cendrawasih can be viewed in many ways as a large marine lake, with a relatively stable environment but genetically and oceanographically isolated populations that are in many ways proceeding on their own evolutionary trajectory.

OUTCOMES AND INDICATORS

Sea-surface-temperature monitoring in the Bird's Head Seascape revealed dramatic differences in the oceanography of Cendrawasih Bay, Raja Ampat, and the Kaimana Corridor. The results highlighted the need to manage these areas carefully, taking into account future temperature increases as a result of global climate change.

Temperature loggers have shown that hard corals in Raja Ampat are exposed to an amazing variation of nearly 17° C, suggesting that this region in particular likely has high resilience to climate-change-related temperature rise. Loggers have helped identify both cold-water upwelling areas and lagoonal and shallow-bay areas that are exposed to huge variations of temperature — both of which have been incorporated into the design of a network of seven marine protected areas in Raja Ampat that should show maximum resilience to global climate change.

Unlike in other areas in Indonesia and southeast Asia, high temperatures were not recorded here during the El Niño–La Niña event in 2009–2010. However, the normal annual cooling (typically May–August, during the southeasterly monsoon) did not occur, and temperatures remained more or less stable or slightly decreased.

Sea-surface-temperature monitoring has been expanded in select areas (including Kaimana and the Ayau area of Raja Ampat), using new loggers with expanded memory capacity. This work was done in close collaboration with Gandi Purba at the local university UNIPA, and she has taken over nearly all collection in Cendrawasih and management of the temperature data.

STORYTELLING

Two important discoveries stemmed from this study. The first was the amazing temperature variations experienced by corals living in the many unique shallow lagoons and bays of Raja Ampat, while the second is the depression of seasonal cooling during the end of an El Niño year (which also corresponded with bleaching events elsewhere in Indonesia). Raja Ampat's reef system includes expansive shallow-water formations, most of which have highly restricted water circulation and show super-heating during the day and dramatic cooling in the evening. For example, the shallow lagoon of Walo Island in the Kofiau complex, which has at least 20 species of reef-building hard corals thriving within it, is exposed to an incredible range of temperatures of nearly 13° C — from 23.18 to 36.04° C — often in the space of a single 24-hour period!

Other similar areas discovered by this study include Mayalibit Bay, Sorong Bay, and the "blue water mangrove" areas in southern Gam Island (Dampier Strait region) and Nampale Island off NW Misool in southern Raja Ampat. The intertidal reef flats in Raja Ampat were also exposed to wide temperature swings of 7 to 8° C on a regular basis. These results suggest that Raja Ampat reef corals (and their symbiotic algal zooxanthellae) have a wide range of temperature tolerances, which should mean maximum resiliency in the face of global climate change. The results of the temperature monitoring (and particularly the identification of upwelling areas and areas exposed to huge variations in temperature) played a very important role in the siting and design of the Raja Ampat MPA Network, which now includes seven MPAs that incorporate all of these most important variable-temperature sites.

The documentation of a cooling depression during the tail end of an El Niño at the same time that there were severe bleaching events throughout the rest of Indonesia points to the possibility that corals rely on "winter" or the physiological relief offered by periods of cool-water flushing. Oceanographic considerations of bleaching conditions typically focus on warm-water events, whereas the lack of cool-water events may be equally important. Raja Ampat did not show significant bleaching during this event, perhaps because both warming and lack of cooling may work in concert to trigger these events.

This developing picture of the isolation of Cendrawasih is underscored by recent work on hard coral specimens collected during the 2006 rapid assessment of Cendrawasih Bay. Taxonomic work now shows that Cendrawasih is home to a range of new and endemic coral species and even a new genus of hard coral that is in many ways a "missing link" between *Acropora* and *Astreopora*.

PROJECT 5: AERIAL SURVEYS OF MARINE RESOURCE USE AND LARGE MARINE FAUNA IN RAJA AMPAT (CONSERVATION INTERNATIONAL)

BACKGROUND

Raja Ampat boasts an expansive network of marine protected areas (MPAs) totaling more than one million hectares. While this scale is ideal for the protection and recovery of animals ranging from tiny coral polyps to migratory marine mammals, it presents challenges for management. Outlying areas may be fished, depleted, and damaged without timely detection. Many large animals are exceedingly shy, thereby evading standard monitoring activities. Additionally, fishers breaking the law may hear or see community-based survey boats coming in time to hide illegal fishing gear, explosives, poisons, or other important evidence. Creative approaches are needed when monitoring resource use and large animal activity in Raja Ampat's MPAs — in particular the distant regions.

During Phase I of the BHS EBM Program, more than 60 hours and almost 10,000 kilometers of aerial surveys were conducted, providing an overview of marine resource utilization patterns and megafauna space use in Raja Ampat. The placement of seven MPAs declared by the Raja Ampat government in May 2007 reflected these aerial observations, ensuring the protection of fish aggregations as well as important habitats for large threatened animals such as manta rays, cetaceans, and dugongs.