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NIWA has recently initiated a mooring program to investigate the temporal coupling between surface and deep ocean processes in the SW Pacific Ocean, on timescales of days to years. Two biophysical moorings have been established in 3-kilometer deep subtropical and subantarctic waters, east of New Zealand, since October 2000. The moorings each comprise a near-surface fluorometer, current meter, thermistors and a temperature/conductivity sensor (since March 2001) in the top 200 m with a time-incremental sediment trap and current meter at 1500 m water depth. These moorings have been serviced on a 4-5 monthly basis for the past year, generating a detailed time-series of surface productivity and export production for southern, temperate mid-latitudes.

Initial data from the subtropical site, located in the nominal center of the Wairarapa Eddy, show that substantially higher currents were experienced than expected, resulting in subduction of surface sensors to 600+ meters. Conversely, flows at the subantarctic site were generally <10 cm s-2, resulting in a more stable mooring configuration. Efforts are currently being made to minimize subtropical mooring instability. Preliminary data from subantarctic waters indicate substantially higher levels of surface chlorophyll a (up to 1 mg m-3) than previously recorded from shipboard sampling and satellite remote sensing. The subsurface expression of this early summer chlorophyll maxima in mid-December 2000 in subantarctic surface waters was manifested in a peak POC flux at 1500 m in early January 2001 - about 20 days later. Temporal relationships of the biophysical information generated from the moorings with remotely sensing satellite data (sea-surface temperature, ocean color) and our mechanistic understanding of ecosystem functioning in subtropical and subantarctic waters will enable the single-point data generated by the moorings to be placed in a regional context. This will perhaps allow extrapolation of these observations to encompass the broader extent of the water masses in the SW Pacific Ocean.

### OS21E-96 0830h POSTER

### Autonomous Ocean and Weather Monitoring System: Modular Sensors for Oceanographic Research on Platforms of Opportunity

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The International SeaKeepers Society has developed an autonomous ocean and weather monitoring system. Systems are currently deployed on private super yachts, and commercial cruise ships, which participate in the NOAA VOS (Volunteer Observing Ship) program. Weather, SST, ships position, and other parameters are reported automatically at regular intervals to the SeaKeepers gateway computer and are available within hour after recording to users such as the National Weather Service.

The system is designed to accommodate a wide variety of oceanographic sensors within the instrumentation module. The standard installation has a single sensor package which measures and logs salinity, temperature, pressure and has options for dissolved oxygen, pH and Eh. Optical sensors for chlorophyll and CDOM fluorescence and turbidity have been miniaturized for this application and are under evaluation. Other sensors for pCO2, total CO2 and trace metals are in development and preliminary testing is underway.

The SeaKeepers system and its member vessels offer unique platforms for oceanographic research which can provide low-cost access to: specific regions of the ocean, simultaneous measurements over a wide area and repeated cruise tracks for time studies on weekly, monthly and yearly time schedules. The Society supports and promotes the development of new sensor technologies and data applications that complement the SeaKeepers Society non-profit missions.

URL: http://www.seakeepers.org

### OS21E-97 0830h POSTER

### Mapping the Regional Variability of the California Current Acoustically Using a Waveform Inversion Method

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From May 1999 to May 2000, an ocean tomography experiment was carried out to study both the signal fluctuations in a long-range acoustic transmission and the baroclinic variability of the California Current System in the Northeastern Pacific Ocean. Acoustic signals were transmitted once every four days by a low-frequency sound source moored on top of Hoke Seamount, approximately 600 km offshore from the California coast. The signal recorded by a coastal SOSUS receiver at Point Sur, California show stable and identifiable acoustic arrivals through out the year. The extracted time series of travel time representing direct measurements of the path averaged ocean temperature show seasonal variations that are consistent with historical data and theoretical concepts. A full-waveform inversion of the acoustic arrivals further reveals the spatial and temporal variations of the heat contents. In this presentation, we give a physical oceanography interpretation of the tomography inverse results in combination with other oceanographic measurements. [Research supported by NOPP and by ONR.]

### OS21E-98 0830h POSTER

### Implementation of the Gulf of Maine Ocean Observing System (GoMOOS)

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The Gulf of Maine Ocean Observing System (GoMOOS) has been established as a sustained, real-time observing system that includes a comprehensive array of moored physical and optical sensors, shore based long-range HF radar systems, circulation and wave modeling, satellite observations, and web delivery of data and data products. The first elements of the observing system were installed in July 2001, and the data may be accessed hourly via the web at gomoos.org.

The GoMOOS moored array presently consists of 10 solar-powered, automated buoy systems that telemeter data hourly via cellular phone or GOES satellite transmitters. The buoys are deployed within the major bays and estuaries of the Gulf, along the Continental Shelf from Nova Scotia to the western Gulf, and in the central Jordan Basin. The buoy system measures standard meteorological parameters, as well as fog, and a comprehensive set of surface and subsurface optical and oceanographic parameters. Included in the measurement set are temperature, salinity, and flow velocity at multiple depths, and spectral irradiance, spectral radiance, and chlorophyll fluorescence, and multi-wavelength attenuation and absorption . Data from deep sensors is telemetered up the mooring cable via inductive modem to the buoy data system. The buoy system is designed with a flexible and modular architecture that is capable of handling on the order of 100 subsurface sensors.

The principal technical elements of GoMOOS will be discussed, and the directions of future development of the observing system will be outlined.

URL: http://gomoos.org

### OS21E-99 0830h POSTER

### In Situ Determination of Oxygen and Nitrogen Concentrations in the Upper Ocean

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Total gas pressure, oxygen, temperature and salinity were measured at 50 meters on a mooring at the Hawaii Ocean Time-series (HOT) station from January through September of 1997 and 1998 using a Gas Tension Device (GTD) and a CTD-oxygen sensor (GTD-CTD-$O_2$ instrument package). Our goal was to evaluate the precision and accuracy of the in situ total gas and oxygen measurements and to assess their utility for remotely determining net biological oxygen production in the euphotic zone. By calibrating the oxygen sensor approximately every month during periodic visits to the mooring it was possible to remotely measure the time history of the partial pressures of nitrogen and oxygen to within $\pm$ 0.5 % accuracy as assessed by independent determination of nitrogen concentration. Oxygen changed at 50 meters by 2-4 % in a series of episodes with durations of 1 - 3 months, indicating the discontinuous nature of net oxygen production and the probable decoupling of oxygen production and respiration in the euphotic zone. The GTD and $O_2$ measurements together can be used to distinguish the effects of physical processes and net biological oxygen production on the oxygen concentrations. The largest uncertainty in the coupled $O_2$ and total gas pressure measurements is the drift of the oxygen sensor, making frequent calibration presently a necessity. With more complete vertical coverage in the upper ocean it should be possible to use this approach to determine depth-integrated net oxygen production in the euphotic zone and upper thermocline respiration.

TUE

## OS21F HC: Hall III Tuesday 0830h

## Coral Reef Habitats: New Insights From Integrated Coastal Science III

*Presiding:* **M Field,** University of California, Santa Cruz**; P Jokiel,** University of Hawaii at Manoa

### OS21F-105 0830h POSTER

### An Approach to Merging Remote Sensing with In Situ Monitoring in Assessing the Status of Coral Reef Ecosystems

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Combined with expert interpretation, aerial photography is an accessible and proven method for coral community mapping, but typically requires labor-intensive film processing and manual georectification of many individual photographs. Satellite or aircraft-based remote sensing has been proposed as a means to create maps that capture regional reef status, but attempts to do so may be confounded by inadequate spatial resolution and the corruption of spectral signals in the water column. Also, the mapping of coral reef communities with remote sensing typically does not fully exploit the expert knowledge possessed by coral reef biologists involved in the field monitoring of coral communities.

The NASA EAARL Digital Camera Mapping System (DCMS) adapts remote sensing to enable close integration with in situ monitoring programs such as CARICOMP or Reef Check. Rather than attempting to automate the creation of contiguous and detailed benthic classification maps over large regions, the NASA DCMS creates low altitude, georectified digital camera mosaics over numerous monitoring sites that serve as waypoints along pre-programmed flight tracks. The NASA DCMS combines three components: 1) a light aircraft equipped with a precise navigation system, a continuously operating downlooking digital camera, and an array of GPS receivers for aircraft location and attitude determination, 2) a dedicated processing program that combines apriori geographical information with aircraft digital photography, flight trajectory, and attitude data sets to create numerous, highly detailed

image maps centered over pre-defined monitoring sites, 3) and expert interpretation by coral reef biologists familiar with the overflown monitoring sites.

The remote sensing strategy of the NASA DCMS is based on highly accurate aircraft geopositioning to enable automatic georectification and multiple image mosaic creation targeted at established monitoring sites that may be widely distributed throughout a reef tract. Interpretations of these image maps by local field experts could enable the monitoring of detailed change at key sites throughout large regions.

### OS21F-106 0830h POSTER

### Satellite Observations of Thermal Stress on Coral Reefs

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17 years (1985-2001) of Advanced Very High Resolution Radiometer (AVHRR) Pathfinder sea surface temperature (SST) observations at 9 km resolution reveal areas of significant excessive thermal stress in the vicinity of many of the world's major coral reef ecosystems. The AVHRR data are used to determine "hotspot" anomalies, areas where the ocean temperatures exceed the typical summer maximum SSTs. Time series of the coral reef SST hotspots indicate some regions are repeatedly exposed to temperatures greater than the typical maximums experienced at those sites, possibly resulting in extensive coral reef bleaching and mortality. The occurrence of these SST hotspots is quantified and summarized in a frequency metric that highlights which reefs are most often subjected to thermal stresses during this period. While other ecological and environmental parameters play important roles in coral mortality, clearly thermal stress is a key factor. In situ observations of SST and coral bleaching are presented to determine the extent to which satellite-based temperature measurements are capable of identifying coral reef bleaching.

### OS21F-107 0830h POSTER

### Effects of Turbidity and Sedimentation on Physiological Health and Biodiversity of Corals on the Great Barrier Reef

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A series of surveys and experimental studies was conducted to assess the roles of turbidity and sedimentation on ecological functions in coral reefs. Octocoral biodiversity was determined along and across the whole Great Barrier Reef, by rapid ecological surveys and taxonomic inventories of 161 reefs (361 sites, each 1000 - 4000 square meters in area, and stratified into five depth zones between 0 and 18 m depth). Generic richness decreased with increasing latitude (10 - 24 degrees South) more than two-fold. Across the shelf, richness was highest on mid-shelf reefs, and declined both towards inshore and offshore reefs. Overimposed over this large-scale spatial pattern, richness of zooxanthellate genera was strongly related to water clarity: at any given position across and along the shelf, the richness of zooxanthellate genera was greatest in areas of low turbidity and progressively declined with increasing turbidity. In contrast, the biodiversity of azooxanthellate species was only weakly related, and total cover of octocorals and hard corals were unrelated to turbidity and sedimentation. Experiments demonstrated the effects of short-term and low-level sedimentation, and the effects of different sediment qualities, on the physiology and selective survival of adult hard corals. Both amount and duration of exposure to sediment affected photosynthetic yields (and scope for recovery) of some coastal hard corals. Effects were linear and multiplicative within the range tested (70 - 240 mg per square centimeter, for 12 - 36 hours), thus short exposure to higher levels of sedimentation exerted the same stress as longer exposure to low levels. Synergisms between muddy sediments and marine snow, which both can occur at high concentrations along some inshore areas of the Great Barrier Reef, were found to be responsible for high rates of mortality in 4-weeks old hard coral recruits. This set of studies sheds some new light on the fundamental roles of turbidity, short-term sediment exposure, and sediment quality, on ecological processes in coral reefs. It is estimated that the present-day levels of sediment and nutrient discharge from rivers (averaged over 26 catchments) into the Great Barrier Reef are 4 - 10 fold those of pre-European settlement. The consequences of expanding land use and associated import of sediments and nutrients for the ecology of inshore reefs are being discussed.

### OS21F-108 0830h POSTER

### Use of High-Resolution Pathfinder SST Data to Document Coral Reef Bleaching

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Mass coral bleaching has been observed throughout the tropical oceans to immediately follow periods of thermal stress, possibly in concert with other known causes. Widespread bleaching events in the Pacific and Indian Oceans have been unequivocally correlated to elevated SSTs during strong El Ninos (1982-83, 1986-87, 1997-98). While several important field studies of bleaching have utilized water temperatures monitored in situ to document the relationship of thermal stress to bleaching, many reef sites have insufficient to no in situ temperature data. For such areas, high-resolution satellite-derived SSTs provide invaluable time series data, documenting anomalous environmental conditions, their timing vs. onset of bleaching, and relationship to other measured variables. With the availability of 9km resolution NOAA/NASA Oceans Pathfinder SST data (1985-2001), an internally consistent, calibrated SST database, we can assess the usefulness of SST data to document past conditions in reefs. Statistical analysis of SSTs and limited in situ temperatures from several Atlantic, Indian, and Pacific Ocean locations (each with multiple sites) indicate that 9km SSTs for specific sites, and for the 9 km2 area surrounding each site, are highly correlated to in situ temperatures ($p<0.001$). Observed biases between in situ and night, day and day/night average SSTs are evaluated. Biases are tied, wherever possible, to physical causes, some of which are locality-specific. Pathfinder SSTs are shown to accurately represent in situ temperatures and to provide valuable data for assessing bleaching events at several key sites.

### OS21F-109 0830h POSTER

### Quantitative Morphology of a Fringing Reef From High-Resolution Laser Bathymetry: Southern Molokai, Hawaii

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The fringing reef off the south coast of Molokai, Hawaii, is currently being studied as part of a U.S. Geological Survey multi-disciplinary project that focuses on the health and geologic variability of coral reef systems. As part of this study, we utilized high resolution Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) laser bathymetric data to help improve our understanding the reef morphology. These data provide a basis for mapping and analyzing morphology of reefs with a level of precision and spatial coverage previously unattainable using other methods. By combining the SHOALS bathymetric data with scuba and snorkel surveys, we were able to: (a) determine the large scale 3-dimensional reef morphology; (b) accurately quantify variations in the relief and spacing of spur-and-groove structures along 40 km of reef; and (c) evaluate how spur-and-groove morphology evolves cross-shore from the reef crest to the base of the reef.

The south shore of Molokai hosts an extensive fringing coral reef along the central tow-thirds of the island (~50 km); along the east and west ends there is only a thin veneer of living coral. Along the central part of the island in the wave shadow of Lanai, upward and seaward growth of the reef increases the width of the reef flat and volume of the total reef complex. Mean spur height increases from 1.3 m to 2.7 m between the 5 m and 15 m isobaths while the mean distance between adjacent spur crests (wavelength) increases from 75 m to 118 m between the 5 m and 15 m isobaths. By using color-coded shaded relief spatial models contoured at 0.5 m intervals, we were able to map low relief, high-frequency spurs in shallow depths merging into higher-relief, lower-frequency spurs near the base of the reef. Lastly, we compared the observed trends in reef morphology with variations in modeled wave energy along the reef. Spur relief at 5 m depth is proportional to wave energy, however, between the 10 m and 20 m isobaths the spur relief is inversely proportional to wave energy. Spur-and-groove wavelength at all depths is inversely proportional to wave energy, as is reef flat width and total reef width. It therefore appears that waves exert primary control on both the small- and large-scale morphology of the reef off south Molokai.

### OS21F-110 0830h POSTER

### Use of high-resolution satellite imagery for mapping coral reef bathymetry

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High resolution, multispectral, commercial satellite imagery provides a potentially efficient method of mapping coral reef environments. Effective mapping of habitats in remote areas can be enhanced by using bathymetric data, but data at resolutions and coverage comparable to high-resolution satellite imagery are rarely available. Well-known algorithms exist to determine water depth from passive multispectral satellite imagery, but we have found several complications in applying these algorithms to extensive mapping of benthic coral reef habitat. In order to address these issues, we developed an alternative algorithm that can retrieve depth information in deeper waters than the classic approach (30 m vs 15 m), is simpler to tune with only two parameters (vs. five parameters), and demonstrates greater stability over larger areas and between different atolls. This method produces comparable accuracy in shallow water and can be tuned using extremely limited data. We generated bathymetry maps for Pacific Ocean coral reef atolls in the Northwest Hawaiian Islands and validated with lidar data collected in the same region. The results allow for detection of relatively fine structure in coral reef environments over a variety of depths and several cover types.

### OS21F-111 0830h POSTER

### Effect of Spatial Resolution on Change Detection of Satellite Imagery For Mapping and Monitoring Stressed Corals

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Considering the vast area of Coral Reefs, and the remote nature of many of them, an effective procedure to map and monitor ecosystem stress from satellite imagery is needed. In previous work, we have reported on the use of a spatial homogeneity index, the Getis statistic, for mapping change in surface morphology between image dates that can be related to sources of stress such as pollution. The procedure is not dependent upon in situ optical measurements that typically have been used to correct beam attenuation through the water column in an effort to retrieve spectral signatures.

In this study we report on the analysis of five SPOT images of Bunaken reef in Sulawesi, Indonesia selected over an eleven-year interval from 1990 to 2000. We also have an IKONOS image for 2001 with coincident in situ measurements of water depth, tidal range and water optical properties. We determine the change in reef homogeneity over the decade from the SPOT data, and the IKONOS data resampled to the same resolution, using

the Getis statistic change procedure. We subsequently reapply the Getis statistic to the IKONOS data at increasing spatial resolution to determine whether there is an optimal value for the homogeneity characteristics of this particular reef sample. We also wish to determine whether detailed analysis from the new high resolution imagers may be used with confidence in concert with the historical archive of lower resolution data.

### OS21F-112 0830h POSTER

## Modeling Reef Accretion at Kure Atoll, Northwestern Hawaiian Islands, Using Remote Sensing Techniques and Field Measurements

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Understanding patterns of carbonate production on the scale of entire reefs in marginal environments is critical for assessing the influence of global processes on the health of coral reefs, for understanding the controls on reef distribution worldwide, and for predicting responses to the changing global environment.

Kure atoll in the Northwestern Hawaiian Islands is the world's northernmost atoll (28° 27'), occurring in a marginal environment with respect to SST. We are integrating data from the latest remote sensing technologies and recent field surveys to model carbonate accretion and reef growth at Kure atoll, focusing on patterns of benthic diversity and habitat-specific variation in carbonate production. Benthic habitat characterization and maps from satellite and aerial imagery allow calculation of a $CaCO_3$ budget on spatial scales and resolutions hardly possible a decade ago, i.e. that of the entire atoll ecosystem. Field data provide input for parameters not measurable with remote sensing techniques, such as coral and coralline algal growth and bioerosion rates.

We are using high resolution IKONOS satellite imagery, acquired in 2001, to produce benthic habitat maps aimed at discriminating and determining the total aerial cover and locations of the dominant framework builders (live coral and coralline algae). Groundtruthing of the benthic habitat classifications is based on extensive GPS-coded tow-board video surveys and classic transect and quadrat ecological studies to estimate composition and percent cover of benthic communities. A field library of spectral reflectances of dominant benthic organisms is being used to aid analysis and interpretation of the imagery. Results of the field surveys, coupled with the remote sensing imagery, suggest that Kure atoll may have higher coral and coralline algal cover than previously suggested. A high abundance of framework reef bioeroders was also observed and their effects quantified for future input to the model. In addition, coral cores (30-40 cm long) were recently extracted from large massive corals at Kure and neighboring atolls to provide historical records of coral growth rates. Those data will shed new light on the corals' responses to the changing conditions (SST, $CO_2$) of recent decades.

Kure' s location at the threshold of the present range of environmental conditions suitable for reef growth presents unique biological and geological aspects, and provides an ideal environment to investigate the mechanisms of reef accretion, and those that limit reef distribution. This research will provide new insights to predictions of Kure's present ability to keep up with, or succumb to, expected sea level changes.

### OS21F-113 0830h POSTER

## Five Years of monitoring reefs: What has Reef Check told us?

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Reef Check, the global coral reef education, monitoring, and management program, was founded in 1997 as a volunteer initiative to help local communities monitor coral reef health using a standard and scientifically rigorous method. The Reef Check survey method is designed to be carried out by recreational divers trained and led by marine scientists. Divers count ecologically sensitive and easily identifiable organisms including grouper, lobster, humphead wrasse, barramundi cod, edible sea cucumbers, giant clams, and live coral. The absence or presence of these organisms indicate specific impacts on the reef, such as overfishing, blast or poison fishing, and collection for curios and the aquarium trade. By providing an annual, synoptic view of coral reef health, Reef Check provides crucial data to scientists and resource managers. In 2000-2001, surveys were conducted using standard Reef Check methods on over 500 reefs in 48 countries and territories. Results were consistent with those found in 1997 -1999. With few notable exceptions, reefs found inside marine protected areas are not significantly healthier than unprotected reefs. This result confirms that most coral reef MPAs, which are found in developing countries, are not yet achieving their conservation goals. Worldwide, the greatest impact to reefs is overfishing; reductions in numbers of fish and indicator organisms were reported at most survey reefs. The five-year results show that few reefs, even among those at remote locations, remain unaffected by anthropogenic impacts. In addition to the annual survey of reef health, Reef Check teams are developing and implementing environmental education and community outreach programs to help promote stewardship of coral reef resources among local community groups worldwide.

URL: http://www.reefcheck.org

### OS21F-114 0830h POSTER

## Mapping Benthic Habitat of Pacific Ocean Coral Reefs with High Resolution Satellite Imagery

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Synoptic information for mapping and monitoring shallow water coral reef environments is now available from high-resolution satellite imagery. Commercially available, 4 m spatial resolution, multispectral imagery is used to create benthic habitat maps for the extensive reefs in the Northwest Hawaiian islands (NWHI), part of a recently declared U.S. marine reserve. The multispectral nature of the imagery is exploited to minimize atmospheric and water surface effects. True-color pictures are generated and bathymetry and bottom albedo are calculated directly from the imagery, to depths of 30 m. The water color, bathymetry and bottom albedo are incorporated into a semi-automated classification process, using a rule-based method and a hierarchical classification scheme to facilitate reproducibility. The resulting NWHI classified maps have a minimum mapping unit of <1000 square meters, over areas ranging from 100-700 square kilometers and reef environments varying from classic atolls to mazes of reticulated reefs without fringing reef protection. The maps are validated with benthic habitat data collected during a NWHI research cruise and results demonstrate that high-resolution satellite imagery interpreted in a rule-based classification system is an effective tool for mapping coral reef habitat.

### OS21F-115 0830h POSTER

## Acoustic Detection of Different Types of Reef Benthos in Broward County, Florida (USA)

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Benthic assemblages of variable density cover three ridges that parallel the Broward County, Florida, coast at about 5-10m, 10-20m and 20-30m depth. Two of these ridges are drowned early Holocene coral reefs of 5 ky and 7 ky uncorrected radiocarbon age respectively. In response to changes in environmental factors (hydrodynamic exposure, ambient light, etc.) the characteristics of benthic assemblages change. An acoustic bottom classification survey using QTCView 5 based on a 50 kHz transducer showed different acoustic classes on the shallow, nearshore hardground and the two deeper reeflines, which showed the same acoustic signature. Rubble beds inshore of the third, deepest reef-line showed a mixed acoustic signature. Ground-truthing by divers utilizing traditional transect surveys showed that the differences in acoustic signature corresponded to different benthic assemblages: nearshore hardgrounds had low live cover (10%) and were dominated by algae and hydrozoa, the two deeper reef lines had the same acoustic signature and similar benthic assemblages (25-50% cover by tall sponges and gorgonians). Subtle differences in species composition existed, however since growth-form characteristics and thus acoustic surface roughness characteristics, were the same in both areas, no acoustic split was achieved. The QTCView5 was also able to differentiate between stable sands covered by a thin red algae turf and more mobile sand without turf cover. It is therefore concluded that acoustic remote-sensing methods can be used to differentiate different benthic assemblages, as long as enough differences exist in the growth-form characteristics of the dominant species to provide for a unique acoustic roughness.

### OS21F-116 0830h POSTER

## Mapping of Holocene reefs in Southeast Florida (USA) by remotely sensed optical and acoustic data together with in situ techniques

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Using a combination of laser based (LIDAR, LADS) and multibeam sonar bathymetry, acoustic and optical remote-sensing, together with in situ observations, the Southeast Florida (Broward County, USA) subtidal was investigated to over 200 m depth. Five well-developed and sequentially deeper coast parallel ridges were mapped. An inshore ridge at approximately 5 m depth may be a lithified shoreface or tidal bar. The next two at average depths of 10m and 20 m respectively have their genesis as Holocene reef lines with Acropora palmata frameworks which terminated at roughly 5ky and 7ky uncorrected radiocarbon age. Two deeper ridges were mapped for the first time, one at 45m depth the other at 85m depth. These may be drowned reefs formed during the Holocene transgression. The upper three reefs are separated by sandy area and, in some regions, wide rubble beds.

Both laser and multibeam bathymetry were used to delineate the hardground and sandy areas. Single-beam acoustic seafloor classification using QTCView 5 based on a 50 kHz signal was used to differentiate further between sand, solid rock, and rubble areas. Ground-truthing of remote-sensed interfaces of sand/rubble/rock ("reef edges") employed divers on scooters that towed a WAAS DGPS in a surface buoy allowing the divers to mark waypoints.

Results indicated that: (1) aerial imagery was not suitable for bottom classification due to depth, shading effects, and turbidity; (2) a combination of laser bathymetry and acoustic bottom classification differentiated sand from reef from rubble; (3) continuous, Holocene barrier reef systems exists along the entire length of Broward County (4) rubble beds are discontinuous and likely represent a leeward halo of reef-derived debris formed while the reef grew at or near sea-level; (5) inshore hardgrounds are often repeatedly buried and uncovered by sand; (6) the sand/high-relief-reef interfaces are relatively stable; (7) two deeper unknown hardground ridges, likely drowned Holocene reefs, were mapped for the first time.

### OS21F-117 0830h POSTER

## Measured Volume and Area Loss: A 10 Year Study of the Collapse of Lagoonal Patch Reefs @ Mexico Rocks Patch Reef Complex 1990-2000

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Mexico Rocks Patch Reef Complex (MRPC) is located 0.5 km east of Ambergris Caye, Belize C.A. in 3 m water depth on the outer shelf lagoon west of the barrier reef, and is a typical patch reef complex on the

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northern shelf and is composed of over 100 patch reefs. MRPC experienced mass bleaching in 1995. In 1998, MRPC was bleached again and subjected to Hurricane Mitch. This study reports on changes in patch reef area and volume since 1990 at MRPC.

In 1990 and 2000, the same twenty-three patch reefs from MRPC were biologically surveyed (using modified AGRRAP) and geologically mapped to determine changes in biotic distribution and reef dimensions. Statistical analysis of biotic data collected in 1990 and 2000 indicate that significant differences exist in coral cover, algal cover, and coral distribution, ($p < 0.05$, using paired t-test); whereas, significant geologic changes also exist in cavities, degradation, area, and volume among the 23 patch reefs measured.

Based on weighted percentages for the complex, coral cover decreased 96.4%; whereas, algal cover increased 490.6%. As a result, the complex as a whole is no longer dominated by corals, and the reef composition is better described as a coralgal complex.

Throughout the complex, degradation increased 143.4%, and cavities increased 307.3% from 1990 to 2000. Total area of the twenty three reefs decreased 19.2%, while volume decreased 30%. In general, these dimensional changes occur as degradation and cavities increase. Though the outline of the reefs are still definable, loss of topographic relief is evident as crumbled rubble within all the frameworks. A visual survey (by CDB) of MRPC days after Hurricane Mitch indicated that the hurricane had little or no effect on the reef structure. Therefore, these dimensional changes are the result of vertical and lateral structural failure, not carbonate removal by mechanical processes.

The combination of events that include two hyperthermal episodes and a hurricane have combined to produce a reef system in which erosion, particularly bioerosion, exceeds carbonate production. The phase shift to an algal-dominated reef system has disrupted the coral calcification and erosional equilibrium that was evident prior to the 1995 bleaching event by the keep-up and lateral expansion growth morphology of the patch reefs. Clearly, the carbonate balance that once characterized these patch reef complexes has been compromised. Although MRPC is only one of many complexes on the norther shelf of Belize, all other complexes share similar changes and characteristics. As a result, lagoonal patch reef structures are unstable and collapsing throughout the northern shelf. Ultimately, bleaching may have triggered this collapse; however, this apparently simple explanation is deceptive because the pervasive nature of patch reef demise is apparently related more to algal overgrowth and lack of algal herbivory (components more commonly associated with anthropogenic causes) than to short-lived hyperthermal events.

## OS21F-118 0830h POSTER

### The Metabolic Response of a Coral Reef to Eutrophication

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A major environmental concern is the deterioration and destruction of coral reefs in response to eutrophication. Excess nutrients increase macro-algae biomass, which overgrow and smother corals and other benthic invertebrates often causing their mortality. Calcification rates of corals are reduced and the balance between symbiotic algae and their host corals is disrupted. We measured the community metabolism of the Nature Reserve Reef (NRR), during the naturally occurring annual eutrophication cycle associated with winter vertical mixing in the Gulf of Eilat, Israel. Eutrophication caused an increase in the community gross prodution to respiration ratio ($P_g$:R) accompanied by a factor of 3 decrease in the net community calcification (G) relative to the oligotrophic stratified summer values.

Superimposed on these seasonal cycles we have identified a long term trend of decrease in G between 1990-2001. G decreased from a high value of 200 in 1990/91, to 80 in 1997/98 to 50 in 2000/01 (in units of mmole C $m^{-2}day^{-1}$). The values for NRR in 1990/91 are well within the upper range published for Red-Sea and Indo-Pacific reefs, while the values since 1998 are lower by a factor of 3 to 4.

Other studies reported: 1. A decrease in live coral cover by a factor of 2 between 1995 and 1999 at the NRR, despite the fact that this reef was closed off to public access since 1993. 2. A strong decline in larval recruitment at the same site during the period 1993-2000. 3. Since 1998 nutrient levels have almost doubled in the deep water and phytoplankton productivity in the open sea have increased by a factor of 2-3. All these observations suggest that the Northern Gulf of Eilat is undergoing eutrophication which may have caused all these changes in the NRR.

Community metabolism is a powerful monitoring tool to evaluate the environmental status of coral reefs. The obvious advantage of this method is that it provides early warning of the deterioration of these ecosystems, well before it can be detected in community structure studies. We found that a minimum of two measurements per day of $O_2$ and alkalinity are sufficient to detect community metabolism changes.

## OS21F-119 0830h POSTER

### Upwelling-derived Phytoplankton as a Nutrient Source for Red Sea Reefs

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The Red Sea is a hydrodynamically unique marginal sea. Some of the warmest and most saline waters are created in this region of the world due to the evaporative capacity of the surrounding air and the bathymetry of the northern gulfs of the Red Sea. For example, in the Gulf of Aqaba, inverse estuarine circulation brings in warm Red Sea surface waters and returns denser, deeper waters to the Red Sea. As in many shallow, warm, oligotrophic regions, coral reefs prosper in the northern Red Sea, despite the apparent paucity of nutrients. This "coral reef paradox" has been discussed in many previous publications (e.g. Odum 1971), and most recently by Yahel et al. (1998) and Richter et al. (2001) for the Red Sea. Several investigations indicate that allochthonous phytoplankton are the most likely source of nutrients contributing to the productivity of the reefs (e.g. Yahel et al. 1998, Fabricius et al. 1998, Richter et al. 2001).

The obvious question then becomes, "What is the source of the phytoplankton that are supporting the reef productivity?" The primary objective of this study is to quantify phytoplankton production in the Gulf of Aqaba and assess their potential importance to local coral reef vitality. Because primary production in this arid subtropical region is not limited by light, local hydrodynamics, including upwelling and tidal forcing, determine the timing and location of the major phytoplankton blooms. We examined the relationship between phytoplankton dynamics and physical processes using spatial and temporal patterns of chlorophyll a determined from the Sea-viewing Wide Field of view Sensor (SeaWiFS) and sea surface temperatures obtained from the MODerate resolution Imaging Spectrometer (MODIS).

Spatial averages of chlorophyll a obtained from the central region of the Gulf demonstrate the strength of the seasonal and interannual variability in phytoplankton dynamics. In addition, we found that chlorophyll a and temperature exhibit significant east-west gradients across the Gulf (colder temperatures and higher chlorophyll a along the eastern edge), and that these gradients vary in strength on a seasonal and interannual basis. Due to the prevailing northeasterly winds in the region, these gradients are likely to represent an upwelling signal. Because the Gulf of Aqaba is approximately one Rossby radius wide, with overlapping upwelling and downwelling regions, the strength of these gradients is surprising. In addition, the gradients are not consistent throughout the Gulf; the northern half of the Gulf appears to be more strongly affected by upwelling than the southern reaches. Alternatively, tidal forcing may disrupt the upwelling signal in the southern portion of the Gulf. This is evidenced by the covariation between the areal extent of a warm plume entering the Gulf from the Red Sea basin (presumed to be tidally-forced) and the location and extent of the upwelling signal. To the extent that phytoplankton provide a substantial fraction of the nutrients to the reef community, coral reef productivity may in turn reflect the complex spatial and temporal dynamics of the phytoplankton populations.

## OS21F-120 0830h POSTER

### Evolution of Coloration Determined by GFP-like Proteins in Reef Anthozoa

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The family of proteins homologous to the green fluorescent protein (GFP) from Aequorea victoria exhibits striking diversity of features, including several different types of autocatalytically synthesized chromophore. Here we report eleven new members of the family, among which there are three red-emitters possessing unusual features, and discuss the similarity relationships within the family in structural, spectroscopic and evolutionary terms. Phylogenetic analysis has shown that GFP-like proteins from representatives of sub-class Zoantharia fall into at least four distinct clades, each clade containing proteins of more than one emission color. This topology suggests multiple recent events of color conversion. Combining this result with previous mutagenesis and structural data, we propose that (i) different chromophore structures are alternative products synthesized within a similar autocatalytic environment; and (ii) the phylogenetic pattern and color polymorphism in reef Anthozoa is a result of a balance between selection for GFP-like proteins of particular colors and mutation pressure driving the color conversions.

## OS21F-121 0830h POSTER

### Growth Response of Caribbean Shallow-Water Corals Under UV-Exclusion and Reduced Photosynthetically Active Radiation Experiments

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We measured the linear extension rates of the Caribbean shallow-water branching corals *Acropora cervicornis* and *Porites furcata* which were under excluded ultraviolet radiation (UVR; 280-400nm) in a pristine reef in the southwest coast of Puerto Rico for three consecutive months. Corals were stained with Alizarin Red S just before the beginning of the experiments. Linear extension rates were measured with a vernier caliper from the stain line to the tip of each branch of the colonies. We used a Saran meshes to reduce UVR levels to 4% and Photosynthetically Active Radiation (PAR; 400-700nm) to a 12% of normal intensity levels at sampling depth (2m), and Hyzod panels to block 99% of the UVR reaching the corals and 23% PAR. Both types of treatments were run in triplicates. The control colonies were exposed to the normal UVR and PAR levels at sampling depth. Colonies of both species showed significantly lower linear extension rates under the Saran than the control and Hyzod ones. The colonies of *A. cervicornis* grew a average 3% more under 99% excluded UVR, while *P. fucata* grew 12% more under the same treatment. Although the differences are not significant suggest a possible negative effect of the actual levels of UVR reaching shallow-waters on the growth of branching corals. The results are compared and correlated with a possible bleaching event that might have occurred during the course of the experiments, especially in the colonies under the Saran treatment. These colonies showed a decrease in their zooxanthellae/unit area content as well as a decrease in their respective photosynthetic pigments. This reduction results in lesser resources directed towards calcification, which translates into decreased linear extension rates and possibly more fragile skeletons.

## OS21F-122 0830h POSTER

### The thermal structure in the coral reef in Papeete

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The objective of this study is to understand the circulation of the interstitial water in a coral reef and the exchange of water between the reef and the ocean. Time series and profiles have been obtained in a well bored in the coral reef in Papeete, Tahiti. Time series of temperature were collected every 20 m within a well 130 m deep. Comparison with time series from the ocean are carried out. The data from the reef reflect well the structure of the reef. In the recent reef component, above 90 m, the influence of ocean water can be easily identified. There is a karstic reef component below 90 m where the interstitial water seems more isolated from the influence of oceanic water. For the recent reef component, the vertical structure of the thermal field can be modelled by an electric circuit analogy. This model allows us to deduce the thermal conductivity of the reef.

### OS21F-123 0830h POSTER

## Nutrification levels and Benthic Community Dynamics in Brazilian Coral Reefs

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Coral reefs are undergoing increasing deterioration worldwide, one of the major causes of coral reef demise being nutrification (large increase in nutrient availability changing the center of productivity from the benthos to the plankton). At early stages, nutrification causes phytoplankton blooms, reducing water transparency. Continued nutrient load may cause coral-algal phase shift, with calcification decrease and benthic dominance by deposit and suspension feeders and algae.

To assess nutrification levels in Brazilian reefs, measurements of the distribution patterns of nutrients and chlorophyll concentrations were conducted in three coastal and offshore reefs with distinct nutrient inputs along the south coast of Bahia State. Seawater and porewater samples were analysed for soluble reactive phosphorus, total oxidised nitrogen and reactive silica. Benthic surveys were performed at all sites to investigate the relationships between benthic community composition and nutrient and chlorophyll concentrations. Sampling was undertaken in dry and rainy seasons.

Nutrient profiles for control sites contrasted markedly with those from impacted sites. Results of both seawater and porewater nutrient measurements revealed the occurrence of consistent spatial and temporal patterns. An inshore-offshore gradient reflects the occurrence of land-based point sources, with significant amount of nutrients being delivered by human activities on the coast (untreated sewage and groundwater seepage). Another spatial gradient is related to distance from a localized source of pollution (an urban settlement without sewerage treatment) with two nearshore reefs presenting distinct nutrient and chlorophyll concentrations. Seasonal variations suggest that submarine groundwater discharge (SGD) is the primary source of nutrients for the coastal reefs during rainy season. The data also suggests that the SGD effect is not restricted to nearshore reefs, and may be an important factor controlling the differences between landward and seaward sides on the offshore reef.

Benthic community assessment revealed that turf alga is the dominant group in all studied reefs and that zoanthids are the organisms most adapted to take advantage of nutrient increase in coastal areas. At nearshore reefs, there was a negative correlation between zoanthids and algal abundance and a positive correlation with the amount of available space for settlement. On the offshore reef, correlation of algal cover with both zoanthids and available space were negative, suggesting that hard substrate may be the primary limiting factor for algal settlement and growth in the nearshore reefs. Highly variable physical disturbances (like wave energy and low tide exposure) between landward and seaward reef sides appear to be the factors controlling algal distribution in the offshore reef. Highly spatial variability in coral cover ultimately reflects the patchy distribution of stony corals over the reefs.

### OS21F-124 0830h POSTER

## Effect of Bleaching on Lipid Biomass in two Hawaiian Coral Species

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Bleaching events can result in mass mortality among corals. However, the impact of these events is not consistent throughout the reef: some corals are not affected, while others either recover or die as a result of bleaching. Scleractinian corals acquire photosynthetically derived energy from their endosymbiotic zooxanthellae and store any excess in the form of lipid. Decreases in zooxanthellae and/or chlorophyll *a* during bleaching could result in decreased photosynthesis and energy acquisition. We hypothesize that bleached corals have lower lipid levels than healthy, unbleached corals. Lipid levels were measured in 50 *Porites compressa* and *Montipora verrucosa* corals collected from Coconut Island Reef, Kaneohe Bay, Hawaii following a bleaching event. Bleaching severity was quantified by the concentration of the algal chlorophyll *a* pigment. Results for *P. compressa* were consistent with our hypothesis: lipid levels decreased with bleaching severity. For *M. verrucosa* no change in lipid levels was observed due to bleaching. This suggests that *M. verrucosa* is able to decrease its metabolic rate and its demand for stored lipids during bleaching. Understanding the changes in the lipid biomass of different coral species from bleaching through recovery will enable us to better assess the metabolic effects of bleaching on corals. These results could be useful for identifying bleaching-resistant corals most suitable for conservation.

### OS21F-125 0830h POSTER

## The Impact of Heat-Induced Bleaching on the Fluorescence of a Caribbean Reef-Building Coral

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Seven paired specimens of the Caribbean coral *Montastraea faveolata* were heat stressed in order to evaluate the fluorescent response of green and orange host-based pigments. One sample from each pair was subjected to elevated temperatures for 28 days, followed by a recovery period lasting 53 days. At regular intervals, high resolution (∼400 $\mu$m/pixel) multispectral images of induced fluorescence were recorded at wavelengths corresponding to the target pigments, plus chlorophyll. The imagery revealed that fluorescent signals of both the green and orange pigments were concentrated at polyp centers and declined by 70-90% in regions between polyps. Chlorophyll fluorescence, however, exhibited a rather uniform distribution across the entire coral surface, except around polyp centers, where it decreased by 10-30%. A normalized difference ratio between the green and orange pigments (GO ratio) was developed to facilitate comparison with chlorophyll fluorescence. Subsequent analysis indicated a high correlation between a sustained GO ratio of less than zero and coral death. Furthermore, the GO ratio appears to be a more sensitive bleaching diagnostic than chlorophyll fluorescence and was resistant to contamination from other sources of chlorophyll fluorescence, such as filamentous algae.

### OS21F-126 0830h POSTER

## Oxygen Dynamics in Turf Algae Canopies on Coral Reefs

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Many coral reef systems are dominated by algal turf and macroalgae cover. Because turf algae have high photosynthetic production and respiration rates, this group is particularly important for reef metabolism and may play a central role in controlling the oxygen budget of coral reefs. To better understand turf algae's role, diurnal changes of dissolved oxygen (DO) in the boundary layers over coral reef turf was examined. Small-scale oxygen gradients in turf algae were assessed in a flume using a polarographic oxygen microelectrode. During the daytime, algal photosynthesis enriched the near bottom water with oxygen. Steep gradients from high oxygen concentrations in the bottom boundary layer to lower concentrations in the water column (at saturation) existed during the daylight. Oxygen concentrations within the bottom boundary layer were significantly affected by water velocity and were very dynamic due to altering irradiance levels. At night, algal respiration caused a substantial uptake of oxygen from the seawater, oxygen concentration gradients reversed; and the water within the bottom boundary layer commonly became hypoxic. In situ measurements of dissolved oxygen in the backreef of Discovery Bay, Jamaica also showed diurnal changes and a substratum specific effect. Additionally, a survey was conducted to assess the distribution of algal canopies on the reef of Discovery Bay, Jamaica in winter 1999. The data in conjunction with earlier studies, indicate a slow recovery from an algae-dominated reef system in the 1980's and early 1990's. In particular, a phase shift from macroalgae to turf algae was observed on shallow fore reef sites. A hypoxic bottom boundary layer caused by algal respiration could produce a competitive advantage for algae for substratum and may possibly contribute to the slow recovery of sessile benthic organisms. Together, the results of this study contribute to a broader understanding of the characteristics of turf algae habitats and their demography. Such information is of particular importance because, for many coral reefs, algal cover is expanding as a result of anthropogenic and natural environmental changes.

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# OS21G HC: Hall III Tuesday 0830h

## Zooplankton: Feeding, Growth, and Distribution III

### OS21G-127 0830h POSTER

## Molecular Analyses of Protistan Assemblages From the Sargasso Sea Suggest Radical Community Shifts in Nutrient-Amended Bottle Incubations and Throughout the Water Column

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Studies of protistan growth and grazing routinely involve the containment of natural microbial assemblages in bottles and often include the amendment of seawater samples with nutrients or organic matter (e.g., primary productivity measurements; microbial grazing using the dilution technique). In dilution experiments, protistan grazers are a major source of recycled nutrients. The reduction of grazers by dilution is usually compensated by the addition of inorganic nutrients to promote the same growth-rates of primary producers across the entire range of dilutions. The Sargasso Sea is an oligotrophic region of the Atlantic Ocean characterized by low biomass but high species diversity. Deckboard incubation experiments were conducted in the Sargasso Sea during August of 2000 to determine the effect of bottle incubation, as well as nutrient and organic matter amendment, on the structure of naturally occurring protistan communities. Both nutrient and yeast-extract additions stimulated large blooms of primary producers, measured by the increase of chlorophyll, in experimental treatments. Changes in community composition in the $< 200$ $\mu$m size-class were estimated during 72-hour incubations and throughout the water column using PCR-based techniques including Terminal-Restriction Fragment Length Polymorphism (T-RFLP) and cloning of full-length 18S rRNA genes. Vertical profiles of T-RFLP patterns in the Sargasso Sea suggest dramatic changes in protistan community structure from the surface to the base of the euphotic zone. Analysis of Restriction Fragment Length Polymorphism (RFLP) patterns from the clone libraries suggests that only a small fraction of phylotypes present at the beginning of an experiment survive to the 72-hour timepoint. Previous studies have suggested that amendment of seawater with nutrients and organic compounds reduces the diversity of natural populations by encouraging the growth of weed-like microbes. We observed that while amendment caused radical shifts in community composition the overall diversity of the protistan community remained similar to starting conditions.

### OS21G-128 0830h POSTER

## Do Growth Rates of Antarctic Protists Compensate for low Temperature?

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Growth rates of aquatic microorganisms in coastal waters off Antarctica are potentially limited by perennially low temperature, yet the importance of this effect for the growth rates of Antarctic protists (microalgae and protozoa) is not well characterized. The

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