

## APPENDIX 29

### Literature Citations & Annotations by Topic

#### Carbon Dioxide & Carbon Dioxide Rise

Bates, N. R. 2002. Seasonal variability of the effect of coral reefs on seawater Carbon Dioxide and air-sea Carbon Dioxide exchange. *Limnology and Oceanography* **47**: 43-52.

Bermuda coral reefs act as a source of carbon dioxide to seawater surrounding the reef but aren't necessarily a source to the atmosphere. Researchers investigated the amount of carbon dioxide the reefs provided to the surrounding waters which vary seasonally in response to coral and macroalgal dominated states. Overall, the status of the reef and whether it acted as a source or sink depended on the pre-existing air-sea carbon dioxide disequilibrium of the open ocean water surrounding the area.

Description of work: Field. Location: Caribbean. Keywords: Coral Reef, Carbon Dioxide, Calcification, Source, Sink

Broecker, W. S., T. Takahashi, H. J. Simpson and T. H.-. Peng. 1979. Fate of fossil fuel carbon dioxide and the global carbon budget. *Science* **206**: 409-418.

The authors examine the assumptions associated with estimates of the transfer of excess CO<sub>2</sub> from the atmosphere to other reservoirs. They state the fate of fossil fuel carbon dioxide released into the atmosphere depends on the exchange rates of carbon between the atmosphere and: the oceans, shallow-water sediments, and the terrestrial biosphere. Estimates of global carbon budgets over the last 20 years are also evaluated. Conclusions were that although models appear to give reliable and consistent estimates for carbon dioxide uptake by the oceans, there is no compelling evidence which establishes that terrestrial biomass has decreased at a rate comparable to fossil fuel combustion.

Description of work: Review. Location: None. Keywords: Carbon dioxide, Fossil fuels, Atmosphere, Ocean waters, Global carbon budget

Frankignoulle, M., C. Cannon and J.-P. Gattuso. 1994. Marine calcification as a source of carbon dioxide: positive feedback of increasing atmospheric CO<sub>2</sub>. *Limnology and Oceanography* **39**: 458-462.

Calcification is a source of CO<sub>2</sub> to surrounding waters and thus is a potential source of atmospheric CO<sub>2</sub>. The authors report an analytical expression which enables the computation of the precipitated carbonate ratio (released CO<sub>2</sub>). Calculations show the amount of CO<sub>2</sub> that must be released to equilibrate seawater increases with increasing partial pressure of CO<sub>2</sub> in seawater, which results from human impact on atmospheric CO<sub>2</sub>. At 15°C, the precipitated carbonate ratio increased from 0.55 during the time of glaciation to 0.67 at present and would increase to 0.84 at about A.D. 2030-2050. The precipitated carbonate ratio as a function of *p*CO<sub>2</sub> should be taken into account in models that predict changes in atmospheric CO<sub>2</sub> content.

Description of work: Review. Location: None. Keywords: Coral, Calcification, Carbon dioxide,

## Precipitated carbonate ratio

Gattuso, J.-P., D. Allemand and M. Frankignoulle. 1999a. Photosynthesis and calcification at cellular, organismal, and community levels in coral reefs: A review on interactions and control by carbonate chemistry. *American Zoologist* **39**: 160-183.

This review discusses photosynthesis and calcification in zooxanthellate scleractinian corals at the cellular (pathways and transport mechanisms of inorganic carbon and calcium), organismal (interaction between photosynthesis and calcification; light effect), and ecosystem (community primary production and calcification; air-sea CO<sub>2</sub> exchange) levels. Sections covered include: background information on chemistry and processes, carbonate chemistry, photosynthesis and calcification, cellular pathways of calcium and carbon, effect of global environmental change, and responses and organism and community levels. Overall, the authors conclude the responses of scleractinian corals to short-term changes in a single environmental parameter are reasonably well known, but synergistic effects are difficult to predict.

Description of work: Review. Location: None. Keywords: Coral, Photosynthesis, Calcification, Carbon dioxide, Calcium, Pathways

Gattuso, J.-P. and R. W. Buddemeier. 2000. Ocean biogeochemistry: Calcification and CO<sub>2</sub>. *Nature* **407**: 311-313.

Reef-building corals, coccolithophorids, and coralline algae are responsible for over half the world's calcium carbonate production. Given their widespread global distribution, it is likely that carbonate biogeochemistry and ecology of the ocean will be affected by rising CO<sub>2</sub> levels. Rising CO<sub>2</sub> levels have two antagonistic effects: the amount of CO<sub>2</sub> generated by calcification will decrease as a result of decreased rates of calcium carbonate precipitation, and increased CO<sub>2</sub> shifts the seawater carbonate equilibria resulting in more CO<sub>2</sub> released per mole of calcium carbonate precipitated. Overall, photosynthetically coupled calcification and its sensitivity to ocean chemistry needs further exploration. Also, marine biological responses (physiological acclimatization and genetic adaptation) to high levels of CO<sub>2</sub> need to be investigated for the long-term, as well as interactions of CO<sub>2</sub> with environmental changes such as increased temperature and nutrient concentrations.

Description of work: Review. Location: None. Keywords: Coral Reefs, Carbon dioxide, Calcium Carbonate, Calcification

Gattuso, J.-P., M. Frankignoulle, I. Bourge, S. Romaine and R. W. Buddemeier. 1998. Effect of calcium carbonate saturation of seawater on coral calcification. *Global and Planetary Change* **18**: 37-46.

The authors investigated the effect of calcium carbonate saturation state on the calcification rate of two reef-building corals, *Stylophora pistillata* and *Acropora* sp. The calcium concentration was manipulated to create changes in aragonite saturation from 98% to 585%. A nonlinear increase in calcification rate as a function of aragonite saturation level occurred. Calcification increased 3-fold when aragonite saturation increased from 98% to 390%. These results

suggested: the rate of calcification does not change within the range of saturation levels corresponding with the last glacial-interglacial cycle, and calcification may decrease in the future as a result of decreased saturation levels due to anthropogenic release of CO<sub>2</sub> into the atmosphere.

Description of work: Laboratory. Location: Mediterranean. Keywords: Coral, Calcification, Aragonite saturation, Carbon dioxide

Gattuso, J.-P., M. Frankignoulle and S. V. Smith. 1999b. Measurement of community metabolism and significance in the coral reef CO<sub>2</sub> source-sink debate. *Proceedings of the National Academy of Sciences* **96**: 13017-13022.

Assumptions involved in the pH-total alkalinity (pH-TA) and pH-O<sub>2</sub> techniques are examined to assess the effect of reef metabolism on the global carbon cycle in the short and long term in this review. The study concludes that: the pH-TA method remains widely applicable in most reef systems, coral reef flats are sources of CO<sub>2</sub> to the atmosphere, and that coral reefs were not an important component of the global carbon cycle but they do play an important role in the long-term control of atmospheric pCO<sub>2</sub> by releasing significant amounts of CO<sub>2</sub>.

Description of work: Review. Location: Australia, Asian-Pacific. Keywords: Coral reef metabolism, Carbon dioxide, Source-sink, pH-total alkalinity, pH-O<sub>2</sub>

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* **301**: 929-933.

Current knowledge of the worldwide status of coral reefs is reviewed in respect to human threats, new directions for research, and management. Projected increases in carbon dioxide levels and sea temperatures over the next 50 years exceed the conditions under which coral reefs have flourished in the past. However, reefs will not disappear entirely, but will change; with some species showing greater tolerance to bleaching than others. Topics discussed are: bleaching; acclimation and adaptation; the geological record; managing coral reef resilience; and research and management challenges.

Description of work: Review. Location: None. Keywords: Coral reefs, Climate change, Human impact, Temperature, Carbon dioxide, Management

Kawahata, H., A. Suzuki and K. Goto. 1997. Coral reef ecosystems as a source of atmospheric Carbon Dioxide: evidence from PCO<sub>2</sub> measurements of surface waters. *Coral Reefs* **16**: 261-266.

Measurements of the partial pressure of carbon dioxide (pCO<sub>2</sub>) were taken in oceanic and lagoonal surface waters of the Asian-Pacific. Measurements were used to determine the net effect of the reef systems on air-sea CO<sub>2</sub> exchange. Lagoonal surface waters had a higher pCO<sub>2</sub> than in the surrounding oceanic water. Indications show these reefs were sources of atmospheric CO<sub>2</sub> rather than carbon dioxide sinks.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral Reef, Carbon Dioxide, Calcification

Kleypas, J. A., R. W. Buddemeier, D. Archer, J.-P. Gattuso, C. Langdon and B. N. Opdyke. 1999. Geochemical consequences of increased atmospheric Carbon Dioxide on coral reefs. *Science* **284**: 118-120.

The topic of reef calcification and carbon dioxide is discussed in this review. The calcification of a coral is necessary for its reef-building capacity. Declines in calcification mean declines in reefs. Calcification is dependent on the saturation state of the carbonate mineral aragonite. An increased concentration of carbon dioxide will decrease aragonite saturation in tropical corals, leading to decreased calcification.

Description of work: Review. Location: None. Keywords: Coral, Calcification, Aragonite, Atmospheric carbon dioxide, Calcium carbonate

Langdon, C., W. S. Broecker, D. E. Hammond, E. Glenn, K. Fitzsimmons, S. G. Nelson, T.-H. Peng, I. Hajdas and G. Bonani. 2003. Effect of elevated CO<sub>2</sub> on the community metabolism of an experimental coral reef. *Global Biogeochemical Cycles* **17**: 11-1 to 11-14.

The effect of elevated pCO<sub>2</sub> on the metabolism of a coral reef community dominated by macroalgae was investigated. The experiment took place at the Biosphere-2 facility. The carbonate chemistry of the water was manipulated to simulate present-day and future CO<sub>2</sub> conditions. The pCO<sub>2</sub> level of the future condition was elevated to almost double the pCO<sub>2</sub> of the present-day level. Nutrient levels were low and typical of natural reefs while temperature and salinity were held constant. Algal biomass decreased during the elevated pCO<sub>2</sub> conditions compared to present-day conditions. The increase in pCO<sub>2</sub> resulted in a decrease of calcification. Net community production and dark respiration were not affected by elevated pCO<sub>2</sub>. Light respiration increased with increasing pCO<sub>2</sub> indicating that the enhanced respiration in the light was not due to photorespiration. Overall, under natural, undisturbed, nutrient-limited conditions, elevation of CO<sub>2</sub> decreased calcification, stimulated turnover rate of organic carbon (particularly in the light), but did not effect net organic production. The data did not support the hypothesis that an increase in pCO<sub>2</sub> would produce an increase in net production that would counterbalance the effect of decreasing saturation state on calcification.

Description of work: Laboratory. Location: USA. Keywords: Coral reef, Carbon Dioxide, Calcification, Macroalgae, Photosynthesis, Gross production, Light respiration, Community metabolism

Langdon, C., T. Takahashi, C. Sweeney, D. Chipman, J. Goddard, F. Marubini, H. Aceves, H. Barnett and M. J. Atkinson. 2000. Effect of calcium carbonate saturation state on the calcification rate of an experimental coral reef. *Global Biogeochemical Cycles* **14**: 639-654.

The effect of projected changes in seawater carbonate chemistry on the calcification of coral reef

organisms was investigated using a coral reef mesocosm at the Biosphere-2 facility. The net calcification of the system was monitored using measurements of physical and chemical variables (temperature, salinity, light, nutrients, calcium, pCO<sub>2</sub>, TCO<sub>2</sub>, and total alkalinity). The net calcification rate responded to changes in concentration of calcium and carbonate ions. The results suggest that the saturation state is a primary environmental factor influencing reef calcification. No significant differences in the rate of calcification were found when comparing the sensitivity of calcification to short-term (days) and long-term (months to years) exposure to changes in saturation state. This indicated that coral reef organisms were not able to acclimate to changing saturation states. Results from this study predicted a 40% decrease in reef calcification between the years 1880 and 2065 A.D. compared to previous studies which predicted a 14-30% decrease.

Description of work: Laboratory. Location: USA. Keywords: Coral reef, Carbon Dioxide, Calcium carbonate, Calcification, Saturation state

Leclercq, N., J.-P. Gattuso and J. Jaubert. 2002. Primary production, respiration, and calcification of a coral reef mesocosm under increased Carbon Dioxide partial pressure. *Limnology and Oceanography* **47**: 558-564.

Coral sand, scleractinian corals, sea anemones, and calcareous red algae were set up in an open-top mesocosm to test the effect of increased carbon dioxide partial pressure (pCO<sub>2</sub>) on metabolism (primary production, respiration, and calcification). Testing spanned over a period of one month. Increased pCO<sub>2</sub> did not affect the net primary production of the community. Dark respiration increased slightly at high pCO<sub>2</sub> but did not affect the NCP: R ratio. Overall, increased pCO<sub>2</sub> resulted in a decreased rate of calcification and aragonite saturation.

Description of work: Laboratory. Location: Mediterranean. Keywords: Coral community, Primary production, Respiration, Calcification, Carbon dioxide partial pressure, Aragonite

Marubini, F., H. Barnett, C. Langdon and M. J. Atkinson. 2001. Dependence of calcification on light and carbonate ion concentration for the hermatypic coral *Porites compressa*. *Marine Ecology Progress Series* **220**: 153-162.

The influences of light and saturation state on skeleton growth in hermatypic coral *Porites compressa* was investigated. Two experiments were conducted: one with Biosphere 2 ocean water and the other in the Biosphere 2 ocean itself. In the Biosphere 2 ocean, coral nubbins were deployed at 4 depths which corresponded to different light conditions and 3 chemical states; these conditions mimicked the Last Glacial Maximum, the present day, and the year 2100. Calcification rate was positively correlated with saturation state. Calcification rate decreased 30% from the glacial conditions to future conditions. From present day conditions to future conditions, calcification decreased by 11%. Overall, calcification rate decreased at all light levels, indicating that rising carbon dioxide will impact corals at all depths.

Description of work: Laboratory. Location: USA. Keywords: Coral, Calcification, Aragonite saturation state, Photosynthesis, Light, Carbon dioxide

Marubini, F., C. Ferrier-Pages and J.-P. Cuif. 2003. Suppression of skeletal growth in

scleractinian corals by decreasing ambient carbonate-ion concentrations: a cross-family comparison. *Proceedings of the Royal Society B* **270**: 179-184.

Four phylogenetically and physiologically different species of hermatypic coral (*Acropora verweyi*, *Galaxea fascicularis*, *Pavona cactus* and *Turbinaria reniformis*) were cultured under "normal" and "low" carbonate-ion concentrations. The effect on the coral's skeleton was quantitatively measured by calcification rate and microstructural appearance of growing crystalline fibers using a scanning electron microscope. The "low" treatment resulted in suppression of calcification rate and weaker crystallization. However, while calcification rate was uniformly affected across species, the microstructural response was highly species specific: crystallization was most affected in *A. verweyi* and least in *T. reniformis*.

Description of work: Laboratory. Location: Mediterranean. Keywords: Coral, Calcification, Carbonate-ion concentration, Carbon dioxide, Hermatypic coral

Reynaud, S., N. Leclercq, S. Romaine-Lioud, C. Ferrier-Pagès, J. Jaubert and J.-P. Gattuso. 2003. Interacting effects of CO<sub>2</sub> partial pressure and temperature on photosynthesis and calcification in a scleractinian coral. *Global Change Biology* **9**: 1660-1668.

The effects of increased pCO<sub>2</sub> and temperature on photosynthesis, respiration, and calcification were investigated in the scleractinian coral *Stylophora pistillata*. The main objectives of this study were to develop a better understanding of the effects of global environmental changes on the physiology of corals and to predict future effects. Corals were exposed to temperatures of 25°C or 28°C and to 460 or 760 microatmospheres of pCO<sub>2</sub> for five weeks. Chlorophyll *c* and protein remained constant during the experiment, while chlorophyll *a* concentrations were elevated when exposed to the high pCO<sub>2</sub>-high temperature treatment. The cell-specific density increased at high pCO<sub>2</sub> compared to normal levels. Net photosynthesis was affected by both temperature and pCO<sub>2</sub> but respiration was unaffected. Calcification decreased 50% during the high pCO<sub>2</sub>-high temperature treatment. Calcification did not change under normal pCO<sub>2</sub> and high temperature conditions. This finding disagreed with numerous papers that describe a negative relationship between calcification and CO<sub>2</sub>.

Description of work: Laboratory. Location: Mediterranean. Keywords: Coral, Calcification, Carbon Dioxide, Photosynthesis, Global change, Temperature

Smith, S. V. and R. W. Buddemeier. 1992. Global change and coral reef ecosystems. *Annual Review of Ecology and Systematics* **23**: 89-118.

This paper reviews known or probable responses of coral reef ecosystems to global change. Topics discussed include: ecosystem roles and responses; reef responses to environmental variables; pathways of climate forcing; and large-scale, local, scientific, and institutional issues.

Description of work: Review. Location: None. Keywords: Coral reef systems, Global change, Carbon dioxide, Sedimentation, Sea level, Temperature, Light, Salinity, Nutrients

Tans, P. P., I. Y. Fung and T. Takahashi. 1990. Observational constraints on the global atmospheric CO<sub>2</sub> budget. *Science* **247**: 1431-1438.

Data on observed atmospheric concentrations of CO<sub>2</sub> and the partial pressures of CO<sub>2</sub> are combined to identify globally significant sources and sinks of CO<sub>2</sub>. This data is compared with transport fields generated by a circulation model for specified source-sink distributions. The model showed the north-south atmospheric concentration gradient can be maintained only if sinks for CO<sub>2</sub> are greater in the Northern Hemisphere. Differences between the partial pressure of CO<sub>2</sub> in surface waters of the Northern Hemisphere and the atmosphere are too small for the oceans to be a sink of fossil fuel CO<sub>2</sub>. Overall, a large amount of the CO<sub>2</sub> is absorbed on the continents by terrestrial ecosystems.

Description of work: Review. Location: None. Keywords: Carbon dioxide, Fossil fuels, Source, Sink, Atmosphere, Ocean waters

Vecsei, A. and W. H. Berger. 2004. Increase of atmospheric CO<sub>2</sub> during deglaciation: constraints on the coral reef hypothesis from patterns of deposition. *Global Biogeochemical Cycles* **18**: GB1035.

The "coral reef hypothesis" states that carbonate production by reefs on newly flooded shelves contributes to the rise of atmospheric carbon dioxide during deglaciation. The authors reviews previous data and suggests that the "coral reef hypothesis" is an extremely important concept, particularly during sea level rise. Topics discussed are: carbonate production and CO<sub>2</sub> rise; the coral reef hypothesis in the light of new data; contributions to the Holocene climatic optimum; and late Pleistocene climate forcing.

Description of work: Review. Location: None. Keywords: Coral reefs, Carbon dioxide, Deglaciation

Ware, J. R., S. V. Smith and M. L. Reaka-Kudla. 1991. Coral reefs: Sources or sinks of atmospheric CO<sub>2</sub>? *Coral Reefs* **11**: 127-130.

The authors describe the processes which occur during the precipitation or dissolution of calcium carbonate. The precipitation of calcium carbonate results in the sequestering of carbon. This has lead to the conclusion that coral reefs function as sinks of atmospheric CO<sub>2</sub>. However, the precipitation of calcium carbonate is accompanied by a shift of pH which results in the release of CO<sub>2</sub> by coral reefs. Leading to the conclusion that coral reefs are sources, not sinks, of atmospheric CO<sub>2</sub>. In the marine environment, about 0.6 moles of CO<sub>2</sub> will be liberated per mole of calcium carbonate deposited. In the short term (hours to days) most of the CO<sub>2</sub> liberated may be absorbed by biological processes on the reef. Over extended periods (seasons or years) coral reefs are a contributing source of atmospheric CO<sub>2</sub>. By using estimates of coral reef carbonate production, the authors estimate coral reefs release 0.02 to 0.08 Gt C as CO<sub>2</sub> annually. This is about 0.4% to 1.4% of the current anthropogenic CO<sub>2</sub> production from fossil fuel combustion.

Description of work: Review. Location: None. Keywords: Coral, Carbon dioxide, Calcium carbonate, Calcification, Source, Sink

Wilkinson, C. R. 1999. Global and local threats to coral reef functioning and existence: review and predictions. *Marine and Freshwater Research* **50**: 867-878.

This review attempts to predict the consequences of direct and indirect anthropogenic factors affecting coral reefs as the human population and economic activity increase. The focus is on the past 10 years of research papers and reviews. Topics discussed include the effects of: latitude, depth, temperature, salinity, nutrient levels, geological disturbances, storms and other climatic disturbances, freshwater inundation, low tide exposure, predator and disease outbreak, increased sediment loads, organic and inorganic pollution, complex organic and heavy metal pollutants, over-exploitation, oil and petroleum products, engineering and military damage, increased carbon dioxide concentrations, increased UVB radiation, changes in sea level, and weather. The short-term prediction includes reductions in the extent and biodiversity of coral reefs with disruption to cultures and economies dependent on them. The long-term prediction is more encouraging in that coral reefs are resilient and may stabilize as changes to the environment stabilize.

Description of work: Review. Location: None. Keywords: Coral, Anthropogenic factors, Stress, Sedimentation, Pollution, Bleaching, Mortality, Calcification, Carbon Dioxide, Sea Level

Yamada, K., Y. Suzuki, B. E. Casareto and H. Komiyama. 2003. Possibility of high CO<sub>2</sub> fixation rate by coral reef ecosystems. In: Gale, J. and Y. Kaya (eds): Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies **Pergamon**: 817-822.

This paper reports on the effect of increased flow of seawater over coral reefs and estimates potential increases in CO<sub>2</sub> fixation rates world wide. Previous estimates of net rates of CO<sub>2</sub> fixation by reef ecosystems were said to be nearly zero due to a balance between CO<sub>2</sub> fixed by organic carbon production and CO<sub>2</sub> released by organic carbon decomposition and inorganic carbon formation. This study showed net rates of about 7 gC/m<sup>2</sup>/d over coral reefs. This study found photosynthetic rates of corals increased with the increased flow of seawater. The flow rate over the coral reef on the open-sea side was found to be much higher than in a lagoon. The CO<sub>2</sub> fixation rates at the flow rates of 6 and 30 cm/s were compared. At the flow rate of 30 cm/s the CO<sub>2</sub> fixation rate was 3.5 gC/m<sup>2</sup>/d. This value is 2.2 times higher than at the flow rate of 6 cm/s. This fixation rate is only by coral itself. A global estimate of the CO<sub>2</sub> fixation rate could be on the order of 10,000,000-100,000,000 t-C/y.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral reef, Carbon Dioxide fixation rate, Photosynthetic rates, Flow rate, Organic carbon, Inorganic carbon

### **Coastal Ocean Processes/Seasonal Upwelling**

Burnett, W. C., H. Bokuniewicz, M. Huettel, W. S. Moore and M. Taniguchi. 2003. Groundwater and pore water inputs to the coastal zone. *Biogeochemistry*. **66**: 3-33.

This paper reviews submarine groundwater discharge (SGD) studies done from 1993 through 2003. The authors defined the process of submarine groundwater discharge and reviewed global flux estimates and biogeochemical consequences. SGD is defined as "any and all flow of water on continental margins from the seabed to the coastal ocean regardless of fluid composition or driving force." Three general approaches to assessing SGD were reviewed; these included modeling, physical measurement, and tracer techniques. Past groundwater flux estimates were



usually calculated by making a number of assumptions and resulted in large uncertainty values. There is very little data available on the magnitude of SGD flow and exchange in coastal sediments. The authors suggest that new technology, and modeling strategies need to be developed in order to estimate fluxes and differentiate between the factors that influence SGD.

Description of work: Review. Location: USA. Keywords: Heavy metal, Coral, SGD, Coastal upwelling.

Furnas, M., A. Mitchell, M. Skuza and J. Brodie. 2005. In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. *Marine Pollution Bulletin* **51**: 253-265.

A review of phytoplankton growth rates in the Great Barrier Reef (GBR) found that ambient concentrations of N & P were not limiting. The dominant species was found to have potential population doubling rates of <1 day. Estimates of N & P demand by phytoplankton in nearshore waters showed that daily water column nutrient demand far exceeds the average daily amount supplied by benthic mineralization, river input, upwelling events and sewage discharges combined. The fact that nutrients are supplied in pulse events (river plumes) allows for the possibility that for short durations the input amounts may exceed phytoplankton demand. Nutrient limitation and grazing processes accounted for the lack of phytoplankton blooms in GBR waters. Ambient concentrations of N & P remained relatively constant because mineralization and uptake rates were balanced. In general only a small percentage of nutrients from nutrient pulse events reached the reefs or other benthic communities of the GBR. The bulk of the inorganic nutrient load were consumed by phytoplankton and converted to organic forms as they were passed up the food chain. These organic forms of nutrients were often dispersed over large areas and directly responsible for nutrient effects on benthic communities. Because of the rapid uptake of inorganic nutrients, measurements of dissolved inorganic nitrogen or dissolved inorganic phosphorous alone were not suitable for estimating nutrient availability. These values must be combined with accurate measurements of nutrient inputs, consumption, and turnover rates to quantify nutrient flow through the food chain to the point where it affects coral reefs.

Description of work: Review. Location: Australia. Keywords: Nutrient, DIN, DON, DIP, SGD, Upwelling, Mineralization, Benthic, Phytoplankton, Nitrogen, Phosphate

Hu, C., F. Muller-Karger, G. Vargo and M. Neely. 2004. Linkages between coastal runoff and the Florida Keys ecosystem: A study of a dark plume event. *Geophysical Research Letters* **31**: 1-4.

Study of a dark water plume event off the coast of southern Florida using satellite data, rain and river gauges, and ship surveys. It was concluded that the plume was caused by excess rainfall throughout the months of June and August, 2003. The plume was characterized by high amounts of dissolved organic matter and extensive phytoplankton blooms which possibly included *Karenia brevis* cells in the upstream part of the plume. Using a model, the total nitrogen content necessary to sustain the bloom was calculated at concentrations in excess of  $2.3 \times 10^7$  mol. The total phosphorus was calculated in excess of  $1.5 \times 10^6$  mol. The authors suggested that the

nutrients and dissolved organic matter necessary to support the observed phytoplankton bloom were supplied via coastal and river runoff.

Description of work: Field. Location: Florida Keys. Keywords: Coastal ocean processes, Current, Nutrient

Jahnke, R., L. Atkinson, J. Barth, F. Chaves, K. Daly, J. Edson, P. Franks, J. O'Donnell and O. Schofield. 2002. Coastal ocean processes and observatories: Advancing coastal research. Report on CoOp Observatory Science Workshop, May 2002, Savannah GA 1-18.

A report and proposal for advancing coastal research. Weather systems, ocean currents, air-sea exchange, primary and secondary production, ocean mixing, carbon sequestration, tectonic and earthquake cycles, sea floor volcanism, chemosynthetic systems and marine mammal migration are all processes which require more study and a better scientific understanding. Many of these processes are interlinked and occur over a broad range of scales. The authors propose a coastal observing system (COS) to better study these processes. The COS would be a system to relay constant measurements of a wide variety of coastal conditions. These would include meteorologic conditions, geologic, geochemic and biogeochemic interactions, physical oceanographic processes, etc. In addition to these long term data sets, this system would also provide unique insight to episodic and extreme events as they occur. The authors suggest that the COS would provide much needed scientific data and allow for a better understanding of coastal ecosystem dynamics.

Description of work: Location: None. Keywords: Coastal ocean processes, Current

Lee, T. and D. Mayer. 1977. Low-frequency current variability and spin-off eddies along the shelf off Southeast Florida. *Journal of Marine Research* **35**: 193-220.

Eight current meters were set up on the continental shelf off Miami Beach, FL in February of 1973. Mean current flow in shallow water was essentially zero, while in deeper water there was flow of 20 cm/sec to the north. Approximately once a week, eddies from the current caused highly variable low-frequency current oscillations ranging from 2 days to 2 weeks. The authors suggest that these are caused by wind forcing and may significantly affect the total energy balance of the Florida Current.

Description of work: Field and Laboratory. Location: Miami, Florida. Keywords: Coastal ocean processes, Current

Leichter, J. and S. Miller. 1999. Predicting high-frequency upwelling: Spatial and temporal patterns of temperature anomalies on a Florida coral reef. *Continental Shelf Research* **19**: 911-928.

Temperature records were compared for 7, 21, and 33m depths near Conch Reef in the Florida Keys. Temperature variations increased with increasing depth. These temperature variations were used to predict the arrival of internal tidal bores which are mechanisms of upwelling. The frequency and magnitude of the upwelling events varied along the length of the reef slope. The authors suggested that these upwelling events bring increased nutrients, chlorophyll a, and

zooplankton as well as cooler water to the reef.

Description of work: Field. Location: Florida Keys. Keywords: Coastal ocean processes, Current

Leichter, J., S. Wing, S. Miller and M.Denny. 1996. Pulsed delivery of subthermocline water to Conch Reef (Florida Keys) by internal tidal bores. *Limnology and Oceanography* **41**: 1490-1501.

Long term temperature variations were coupled with salinity, chlorophyll a, and nutrient concentration measurements at Conch Reef in the Florida Keys to determine the arrival and composition of internal tidal bores. The arrival of internal tidal bores was linked to a semidiurnal internal tide, making them a consistent feature near Conch Reef. The bores caused upwelling of cool, high salinity water onto the reef. This water, which was transported from below the thermocline, remains concentrated on the reef for up to 4 hours before mixing with surface waters. Internal tidal bores also delivered dissolved nutrients, suspended particles, and plankton across the reef.

Description of work: Field. Location: Florida Keys. Keywords: Coastal ocean processes, Current, Internal tidal bores

Leichter, J. J., H. L. Stewart and S. L. Miller. 2003. Episodic nutrient transport to Florida coral reefs. *Limnology and Oceanography* **48**: 1394-1407.

Internal tidal bores have been discovered to bring cool nutrient rich water to the coral reef slopes along the Florida Keys. Hydrographic, nutrient and algal data from Conch Reef were compared to data from another study monitoring tidal bore activity along the Florida Keys reef tract. Nutrient concentrations in tissue samples from the macroalgae *Codium isthmocladum* were used to evaluate biological responses to nitrogen pulses associated with the tidal bores. The data suggest tidal bores supply N input along the reef tract at  $1.68 \times 10^3$  to  $6.1 \times 10^4$  kg per bore. Estimates of P inputs ranged from  $3.7 \times 10^2$  to  $10.0 \times 10^3$  kg per bore. Total nutrient load to the coral reef tract could be 20 - 40 times greater than the inputs to near-shore waters from anthropogenic sources and storm water run-off.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral, Upwelling

Lekien, F., C. Coulliette, A. Mariano, E. Ryan, L. Shay, G. Haller and J. Marsden. 2005. Pollution release tied to invariant manifolds: A case study for the coast of Florida. *Physica* **210**: 1-20.

Very high frequency (VHF) radar technology was used to locate Lagrangian coherent structures (LCS) in ocean surface currents off of the Hollywood, Florida coastline. LCS determine the spread of any contaminant or material that is confined to the ocean surface. The authors suggested that the location of the base of the LCS along the coastline can be used to minimize the effect of coastal pollution by timing the release of such pollution. Through VHF and mathematical modeling, it was determined that pollution should not be discharged along the coastline near Hollywood if the base of the LCS was north of the point of release. Pollution

discharged into the coastal zone at times when the LCS is north of the discharge point will be contained and circulated within the coastal zone, increasing its impact on this sensitive ecosystem. Pollution discharged at a time when the LCS is not north of the point of release will be rapidly repelled and disbursed into the pelagic sea. The authors suggested that properly timing the release of contaminants would significantly reduce the impact in the coastal zone. Description of work: Field and Laboratory. Location: Hollywood, Florida. Keywords: Coastal ocean processes, Current

Peters, H., K. Shay, A. Mariano and T. Cook. 2002. Current variability on a narrow shelf with large ambient vorticity. *Journal of Geophysical Research* **107**: 1-15.

Current variability was measured along the narrow shelf off Ft. Lauderdale, FL over three months. Current direction was generally north and vorticity was four times the local Coriolis parameter. Two dominant signals, one at 10 hrs and one at 27 hrs were observed along with low-frequency variations of the Florida Current. Both signals had counter-clockwise rotations and oriented northward. The 10 hr signal had a phase speed of 0.85 m/s and wavelength of approximately 27 km. The 27 hr signal had a phase speed of 1.7 m/s with a wavelength of approximately 170 km. Both signals were barotropic out to a depth of 50 m. The 10 hr signal then showed a 180° phase shift at 160 m. The authors stated that the two signals could not be attributed to barotropic instability.

Description of work: Field. Location: Ft. Lauderdale, Florida. Keywords: Coastal ocean processes, Current

Schlöder, C. and L. D'Croz. 2004. Responses of massive and branching coral species to the combined effects of water temperature and nitrate enrichment. *Journal of Experimental Marine Biology and Ecology* **313**: 255-268.

Branching coral species (*Pocillopora damicornis* Linnaeus) and massive coral species (*Porites lobata* Dana) were exposed to different temperatures and nitrate concentrations for 30 days. The response of the coral-zooxanthella symbiosis was studied under the conditions of: high nutrient low temperature (upwelling), low nutrients high temperature (ENSO), and high nutrients high temperature (tropical nutrification). After experimental conditions, 30% of *P. damicornis* and 90% of *P. lobata* remained healthy. *P. damicornis* was significantly affected by nitrate addition while *P. lobata* was significantly affected by water temperature. Under high nitrate, both species exhibited increased zooxanthella volume and chlorophyll contents. High nitrate and high temperature reduced zooxanthellae density for both species. Overall, it was suggested that the slow-growing species *P. lobata* was better able to cope with changing conditions than the fast-growing *P. damicornis*.

Description of work: Laboratory. Location: Gulf of Panama. Keywords: Coral, Temperature, Zooxanthellae, Nitrate enrichment, Sea-warming, Upwelling

Sloviev, A. 2003. Energetic baroclinic super-tidal oscillations on the southeast Florida shelf. *Geophysical Research Letters* **30**: 1-4.

The South Florida Ocean Measurement Center (SFOMC) showed that there are large scale fluctuations in tidal velocity with a period of about 10 hrs. These oscillations did not coincide with the 27 hr intertidal period or the 12 hr semi diurnal period. These fluctuations were seasonally modulated. The author finds this to be in line with the Stommel hypothesis (1965) of a resonant cross-stream internal seiche in the channel between Florida and the Bahamas. The Gulf Stream and its associated eddies may also contribute to the 10 hr time period.

Description of work: Field. Location: Southeast Florida. Keywords: Coastal ocean processes, Current

Szmant, A. M. and A. Forrester. 1995. Water column and sediment nitrogen and phosphorus distribution patterns in the Florida Keys, USA. *Coral Reefs* **15**: 21-41.

As a part of the SEAKEYS program, the distribution of N, P and Chl a from near shore to offshore waters of the Florida reef tract was examined. Five transects were used in the upper keys, two in the middle keys and two in the lower keys. Water and sediment samples were collected over two year period. Sediment N concentrations were generally reduced by half from inshore to offshore, while P increased from inshore to offshore. Two spatial patterns were observed in the combined data for nutrient and Chl a concentrations in the sediment and water column. The first pattern was shown in the upper and lower keys transects. This pattern was characterized by elevated nutrients and chlorophyll concentrations inshore with a drop to oligotrophic levels within 1 km of shore. The second pattern was observed in the middle keys where water column nutrient levels were higher than the upper and lower keys study areas. There was also a much smaller decrease in water and sediment nutrient levels between the inshore and offshore sites. Upwelling may bring as much as 40 times the annual N load and 25 times the P load as compared to the total anthropogenic input to the Florida reef tract. The Florida reef waters studied were below the threshold values of DIN >0.1 uM, PO<sup>4</sup> >.01 uM and Chl a > 0.5 ug/L. Data from this study combined with other recent work suggested that the decline of the Florida coral reefs may be a part of a regional phenomenon associated with global climate change.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral, Sediment, DIN, P, Upwelling

### **Disease/Pathogens/Viruses/Bacteria**

Alcolado, P. M., R. Claro, G. Menendez and B. Martinez-Daranas. 1997. General status of Cuban coral reefs. *Proceedings of the 8th International Coral Reef Symposium* **1**: 341-344.

This paper discusses the current deterioration of Cuban coral reefs near urban and industrial settlements. In some areas, algae were proliferating and dominating at the expense of corals probably from black urchin die-off and high concentrations of phosphate. Current management of Cuban reefs has no formal direction nor has a system or approach in place. Any measures that do exist are not enforced. A new plan is presented containing new legislation for protecting the

marine ecosystems of Cuba.

Description of work: Review. Location: Caribbean. Keywords: Coral deterioration, Management, Legislation, Ecological status, Coral disease, Fisheries

Andréfoüet, S., P. J. Mumby, M. McField, C. Hu and F. E. Muller-Karger. 2002. Revisiting coral reef connectivity. *Coral Reefs* **21**: 43-48.

Authors used satellite ocean color observations to find physical links between coral reefs and movement of water masses. Specifically discussed are: pathways for pollutants, pathogens, and larvae in coral reefs. Following landfall of Hurricane Mitch on the Honduras coast October 1998, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was used along the Meso-American barrier Reef System (MARS). Fresh-water dispersal associated with high precipitation from Hurricane Mitch showed physical connection with coral reefs. Spatial observations are critical in monitoring coral reefs and can help explain impacts of nutrification, gene flow, and disease propagation.

Description of work: Field. Location: Caribbean. Keywords: Coral, Disease, River Plume, Water mass movement, Pathogens, Pollutants, Phase-shift

Antonius, A. and J. Afonso-Carillo. 2001. *Pneophyllum conicum* killing reef-corals in Mauritius: A new indo-pacific syndrome? *Bulletin of Marine Science* **69**: 613-618.

*Pneophyllum conicum* is a coral syndrome which a coralline red alga overgrows living coral tissue. This review addresses the form found in Mauritius which is extremely severe and was considered a novel syndrome and assigned the symbol PNE. It occurs from intertidal reef-crest areas down to over 30 meters in depth. The algae color depends on the light exposure, ranging from a dark purple-red become lighter to purplish light-gray in shallow water. It strongly adheres, and grows over live coral more frequently than areas of bare skeletons or rock. Many shallow-water species have been found afflicted by this algae. Any survey detailing the health of coral reefs in Indonesia should recognize PNE and consider it a coral-killing syndrome.

Description of work: Review. Location: Indo-Pacific. Keywords: Coral reef health, Coral disease, Coral syndrome, Red alga

Antonius, A. and B. Riegl. 1998. Coral diseases and *Drupella cornus* invasion in the Red Sea. *Coral Reefs* **17**: 48.

A large scale ecological investigation of coral reefs in the Gulf of Aqaba in 1996 surveyed 25 reefs. Most were diagnosed as in "good health" however the corals on one reef were suffering from a population outbreak of *Drupella cornus*, a corallivorous snail, and an outbreak of White Syndromes (White Band Disease, Tissue Bleaching, and Shut-Down-Reaction). *Acropora hemprichi*, the most abundant reef-building species in the area, suffered the highest mortality. There appeared to be a strong correlation between snail abundance and disease prevalence. It is unclear if massive coral die-offs due to White Syndromes attract or benefit *Drupella cornus* or whether the presence of the snail promotes an outbreak of White Syndromes among the corals.

Description of work: Field. Location: Red Sea. Keywords: Coral disease, White Syndromes,

White Band Disease, Tissue bleaching, Shut-Down-Reaction, Corallivorous snail

Ben-Haim, Y. and E. Rosenberg. 2002. A novel *Vibrio sp.* Pathogen of the coral *Pocillopora damicornis*. *Marine Biology* **141**: 47-55.

A coral pathogen, *Vibrio coralyticus*, was isolated from the diseased tissue of *Pocillopora damicornis*. *V. coralyticus* was injected into the seawater surrounding live corals or directly onto coral tissue. At 29°C lysis began as small white spots, rapidly spreading so that the entire tissue was destroyed after 2 weeks. Placing a healthy coral next to a diseased coral caused lysis of the healthy coral in 2-4 days, showing this disease was contagious. Temperature was critical for the infectious process; infection/lysis occurred rapidly at 27-29°C, slowly at 26°C, and was not observed at 25°C. Overall, the presence of this pathogen in seawater surrounding a coral reef led to tissue destruction when seawater temperature was increased.

Description of work: Laboratory. Location: Middle East. Keywords: Coral disease, *Vibrio coralyticus*, Coral pathogen, Temperature

Borger, J. L. 2005. Dark spot syndrome: A scleractinian coral disease or a general stress response? *Coral Reefs* **24**: 139-144.

Dark spots syndrome (DSS) is characterized by purple, black, or brown lesions that are circular, ring-shaped, or elongate and found across coral tissue. It primarily affects *Siderastrea sidera*, *Stephanocoenia intersepta*, and *Montastraea annularis*. Long-term monitoring was done using digital photography to assess changes of DSS over time. Findings showed DSS appeared as a general stress response to increased water temperature and therefore can be used as a biological indicator of reef stress.

Description of work: Field. Location: Caribbean. Keywords: Dark spots syndrome, Coral health, Coral disease, Stress response

Bruno, J. F., L. E. Petes, C. D. Harvell and A. Hettinger. 2003. Nutrient enrichment can increase the severity of coral diseases. *Ecology Letters* **6**: 1056-1061.

Results of the first *in-situ* examination of the effects of nutrient enrichment on coral diseases were reported. Nutrient enrichment was achieved using mesh bags with Osmocoat™ fertilizer anchored near the specimens. 10 individual *Montastraea sp* and 10 *Gorgonia ventalina* were categorized into four groups: control, infected control, enriched, and infected enriched. The results of the experiment suggested that moderate increases in nutrient concentrations can substantially increase the susceptibility of corals to diseases.

Description of work: Field. Location: Caribbean. Keywords: Nutrient, Coral, Disease

Cervino, J. M., R. Hayes, T. J. Goreau and G. W. Smith. 2004a. Zooxanthellae regulation in yellow blotch/band and other coral diseases contrasted with temperature related bleaching: *in situ* destruction vs. expulsion. *Symbiosis* **37**: 63-85.

This study investigated the differences between symbiotic zooxanthellae expulsion induced by temperature/related bleaching, and the loss of symbiotic zooxanthellae in corals that were stressed by pathogen-induced diseases, specifically, yellow blotch/band disease (YBD). Changes in the algae of YBD-infected corals were different than changes in temperature bleached corals. In disease-infected corals, no evidence existed of zooxanthellae in the mucus, unlike thermal bleaching where zooxanthellae were evident in the coral surface layer. Zooxanthellae isolated from corals inoculated with YBD showed a 96% decrease in chlorophyll *a* pigments and a 90% decrease in mitotic cell division when compared to controls. So, YBD pathogens target the zooxanthellae and compromise cytoplasmic and organelle integrity, leaving the host tissue intact. Overall, this study suggested that YBD is a coral disease of the symbiotic zooxanthellae and not a disease of the coral host. This study also documented for the first time the discovery of viral-like particles (VLPs) found in the symbiotic algae in *Montastraea* spp. with YBD.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Coral disease, Yellow blotch/band, Zooxanthellae, Pathogen-induced disease

Cervino, J. M., R. L. Hayes, S. W. Polson, S. C. Polson, T. J. Goreau, R. J. Martinez and G. W. Smith. 2004b. Relationship of *Vibrio* species infection and elevated temperatures to Yellow Blotch/Band disease in Caribbean corals. *Applied and Environmental Microbiology* **70**: 6855-6864.

Yellow blotch/band disease (YBD) which affects the major reef-building *Montastrea* spp. corals of the Caribbean was investigated. Bacteria isolated from diseased corals and inoculated onto healthy ones caused signs of YBD to appear. The rRNA genes of the disease were sequenced and found to correspond to four *Vibrio* spp. Increases in water temperatures resulted in an increased spreading rate of YBD on inoculated corals, therefore increasing coral mortality. During high temperatures, infected corals had 50% less zooxanthellae, 80% lower division rates, and a 75% decrease in chlorophyll *a* and *c* pigments compared to controls. Overall, YBD didn't appear to produce the same physiological response as bleaching, it primarily affected the symbiotic algae rather than coral tissue.

Description of work: Laboratory. Location: Florida and Caribbean. Keywords: Coral disease, *Vibrio*, Temperature, Yellow Blotch/Band disease, Bacteria, Zooxanthellae, Bleaching

Dustan, P. and J. C. Halas. 1987. Changes in the reef-coral community of Carysfort Reef, Key Largo, Florida: 1974 to 1982. *Coral Reefs* **6**: 91-106.

Data was collected from permanently marked transects in the Florida Keys to investigate coral reef changes over time. Results showed that populations between 0-9 meters mostly showed change as a result of physical disturbance while populations between 10-21 meters showed change as a result of sedimentation and disease.

Description of work: Field. Location: Florida. Keywords: Coral reef community, Physical disturbance, Sedimentation, Disease

Garrison, V. H., E. A. Shinn, W. T. Foreman, D. W. Griffin, C. W. Holmes, C. A. Kellogg, M. S.



Majewski, L. L. Richardson, K. B. Ritchie and G. W. Smith. 2003. African and Asian dust: From desert soils to coral reefs. *Bioscience* **53**: 469-480.

The authors present an overview of the atmospheric transport of African and Asian dust. They review background information and research which address airborne microorganisms, coral diseases, and atmospheric transport of chemical contaminants as well as suggest mechanisms and strategies of investigation into these topics. The authors hypothesize that dust transport from Africa and Asia to the Americas is a significant factor negatively affecting coral and downstream communities. In addition, it is suggested the quantity of dust has increased and its composition has changed to include synthetic organic chemicals, anthropogenic pollutants, microorganisms, macro and micronutrients, and trace metals.

Description of work: Review. Location: None. Keywords: Coral, Dust, Disease, Nutrient, Pollutant, Microorganism

Griffin, D. W., K. A. Donaldson, J. H. Paul and J. B. Rose. 2003. Pathogenic human viruses in coastal waters. *Clinical Microbiology Reviews* **16**: 129-143.

This review discusses of the occurrence of pathogenic human enteric viruses (transmitted via the fecal-oral route) in marine waters. Topics include: public health risks; virus occurrence and the fate in marine waters; and the evolution of detection assays. Although progress has been made in viral detection methods, problems still remain.

Description of work: Review. Location: None. Keywords: Viruses, Pathogens, Marine environment, Coastal monitoring

Griffin, D. W., C. A. Kellogg, V. H. Garrison and E. A. Shinn. 2002. The global transport of dust. *American Scientist* **90**: 228-235.

This review addresses the effects of dust storms on the Earth. Dust lifted up into the atmosphere is due to storms, but this dust is carrying more than just dirt. Dust particles can carry pollutants such as herbicides, pesticides, bacteria, viruses, and fungi. Estimates show that 13 million metric tons of African dust sediment fall on the North Amazon Basin of South America every year. Dust storms in North Africa also affect air quality in Europe and the Middle East. Investigations into the microbes present in the dust indicate that 25 percent are species of bacteria or fungi plant pathogens and 10 percent are human pathogens. Evidence shows that human health and coral reef communities have been affected by the dust phenomenon.

Description of work: Review. Location: None. Keywords: Coral community, Dust, Herbicides, Pesticides, Bacteria, Viruses, Fungi, Pathogens, Human health

Harvell, C. D., K. Kim, J. M. Burkholder, R. R. Colwell, P. R. Epstein, D. J. Grimes, E. E. Hofmann, E. K. Lipp, A. D. M. E. Osterhaus, R. M. Overstreet, J. W. Porter, G. W. Smith and G. R. Vasta. 1999. Emerging marine diseases- climate links and anthropogenic factors. *Science* **285**: 1505-1510.

This review discusses the prevalence of diseases within marine taxa in order to evaluate if a

recent increase has occurred. Topics addressed include: whether an increase in disease has occurred; what conditions favor disease outbreaks; and what role do the oceans play as incubators of human diseases agents. Overall conclusions are that disease occurrence in the oceans is on the rise and more studies on marine disease need to be conducted in order to understand mechanisms of disease resistance in the marine life.

Description of work: Review. Location: None. Keywords: Coral disease, Anthropogenic factors, El Niño effects, Marine disease, Human activity, Bleaching, Coral pathogen

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld and M. D. Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* **296**: 2158-2162.

This review considers the impacts of infectious diseases and effects of climate change on marine and terrestrial biodiversity. Climate warming, from El Niño-Southern Oscillation events can increase pathogen development and persistence, disease transmission, and host susceptibility.

Topics discussed included: the current and predicted changes in climate as it relates to terrestrial and marine systems, and impacts of climate on disease for plants, wildlife, and marine life.

Description of work: Review. Location: None. Keywords: Coral, Disease, Bacteria, Pathogen, Climate Change, El Niño-Southern Oscillation, Temperature

Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* **265**: 1547-1551.

This review discusses the degradation of coral reefs over the past 20-30 years in the Caribbean. The island of Jamaica is the main focus due to major declines in coral abundance since the 1970's. Topics discussed were: overfishing, hurricane damage, disease and algal blooms, and future implications and prospects. Overall, the author stresses the need for immediate management procedures to be implemented before long-term damage continues.

Description of work: Review. Location: Caribbean. Keywords: Coral, Phase shift, Long-term decline, Overfishing, Hurricane damage, Disease, Algal blooms, Management

Kim, K., P. D. Kim, A. P. Alker and C. D. Harvell. 2000. Chemical resistance of gorgonian corals against fungal infections. *Marine Biology* **137**: 393-401.

*Aspergillus sydowii*, a disease caused by a fungal pathogen, was studied. Corals were experimentally evaluated to investigate natural mechanisms of disease resistance. Antifungal compounds were effective in disease prevention when found in high concentrations and high potency. A specificity of *Aspergillus sydowii* for *Gorgonia ventalina* and *G. flabellum* may indicate a heightened sensitivity to changes in water quality which can compromise disease resistance. The impact of this pathogen was higher on reefs with high nutrient levels and turbidity which indicated water quality as an important factor in host-pathogen interactions.

Description of work: Laboratory. Location: Florida. Keywords: Coral disease, *Aspergillus sydowii*, Coral pathogen, Disease resistance, Nutrients, Turbidity, Water Quality

Kuntz, N. M., D. I. Kline, S. A. Sandin and F. Rohwer. 2005. Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species. *Marine Ecology Progress Series* **294**: 173-180.

In this study, *Montastraea annularis*, *Agaricia tenuifolia*, and *Porites furcata* were exposed to various carbon sources (starch, lactose, arabinose, and mannose) and nutrients (combinations of phosphate, ammonium and nitrate) in order to record different species-specific and carbon-specific pathologies and rates of mortality. Results showed that the three species displayed different pathologies and mortality rates to treatments. This variation in pathological characteristics to stressors showed that visual cues for determining coral health may be misleading. Mortality increased over time with continual exposure to several stressors suggesting that chronic stress may be more harmful than acute. Unlike organic carbon sources, high concentrations of nutrients did not directly kill corals. Overall, the observed variations in coral responses to stressors means that changes on disturbed coral reefs will depend on the type and duration of exposure to the stressor as well as the coral species.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Disease, Stress, Nutrients, Organic carbon, Anthropogenic stress

Kuta, K. G. and L. L. Richardson. 2002. Ecological aspects of black band disease of corals: relationships between disease incidence and environmental factors. *Coral Reefs* **21**: 393-398.

Salinity, water depth, water temperature, nitrate, nitrite, ammonium, soluble phosphate, total phosphate, turbidity, coral diversity, and percent coral cover were measured at 190 sites on 12 patch reefs. Twenty-one of the sites contained a colony with active black band disease and 169 sites contained healthy colonies susceptible to the disease. Water temperature, depth, coral diversity, and concentrations of orthophosphate and nitrite showed statistically significant relationships with the disease.

Description of work: Field. Location: Florida. Keywords: Black band disease, Coral reef ecology, Coral reef health, Salinity, Temperature, Nutrients

Lipp, E. K., J. L. Jarrell, D. W. Griffin, J. Lukasik, J. Jacukiewicz and J. B. Rose. 2002. Preliminary evidence for human fecal contamination in corals of the Florida Keys, USA. *Marine Pollution Bulletin*. **44**: 666-670.

The coral surface microlayer (CSM) was examined to determine if it may provide a useful measure of fecal coliform and enterococci concentrations. Surface water grab samples were taken from four sites in the middle Keys and cultured for enteroviruses. Fifteen mucus samples were also taken from corals at each site. Bacteria levels were much higher in the CSM samples than the associated water column samples. The authors suggested that due to the high rate of decay of bacterial indicators in the water column that the CSM may be a more accurate sampling medium to detect the presence of fecal coliform in coral reef waters.

Description of work: Field. Location: Florida. Keywords: Coral, Nutrient, Fecal Coliform bacteria

Nugues, M. M. 2002. Impact of a coral disease outbreak on coral communities in St. Lucia: What and how much has been lost? *Marine Ecology Progress Series* **229**: 61-71.

A coral disease called plague appeared on the coral reefs of St. Lucia, West Indies in July 1997. This study quantified the abundance and distribution of diseased corals, predicted the impact of disease on the coral population and community structure, and quantified the loss of living coral cover 8 months after the outbreak. A survey of 6 coral species on 3 reefs in March 1998 revealed a disease incidence of 11%. The most affected species were *Montastraea faveolata* and *Colpophyllia natans*, with 19% and 13% of colonies affected respectively. Disease frequency was independent of coral density. Disease incidence and tissue mortality indicated that small colonies were more likely to escape infection, but once infection occurred, they experienced faster mortality. The disease selectively impacted 2 major reef builders, *M. faveolata* and *C. natans*. The combined tissue loss from these two species accounted for more than 90% of the estimated tissue. Of the colonies infected in February 1998, 28% still showed signs of disease in October 1998. If losses are sustained at these rates, plague could cause complete mortality in large coral colonies and progressively deplete coral reef builder species.

Description of work: Field. Location: Caribbean. Keywords: Coral reef, Coral disease, Mortality, Plague, Coral population structure

Nugues, M. M., G. W. Smith, R. J. v. Hooidonk, M. I. Seabra and R. P. M. Bak. 2004. Algal contact as a trigger for coral disease. *Ecology Letters* **7**: 919-923.

Physical contact of coral with the macroalga *Halimeda opuntia* triggers a virulent disease known as white plague type II has caused widespread mortality in most Caribbean reef-building coral species. For this experiment, colonies of *Montastraea faveolata* that were exposed to this algae developed the disease while unexposed colonies did not. Findings suggested the spreading of macroalgae on coral reefs could be the cause of coral diseases over the past decades and reduction of macroalgal abundance could help overall coral health.

Description of work: Field. Location: Caribbean. Keywords: Coral disease, Coral reef, Epizootic, Halimeda, Macroalgae, Overgrowth, White plague

Ostrander, G. K., K. M. Armstrong, E. T. Knobbe, D. Gerace and E. P. Scully. 2000. Rapid transition in the structure of a coral reef community: The effects of coral bleaching and physical disturbance. *Proceedings of the National Academy of Sciences* **97**: 5297-5302.

A 40-month study documented changes in a Caribbean reef community affected by bleaching, hurricane damage, and an abundance of macroalgae. During the study, the reef experienced a mass bleaching event resulting in a decline in coral abundance. Also, macroalgae increased until they dominated the substrate. Hurricane Lili in 1996 may have facilitated this increase in algal abundance. Results showed that a rapid phase shift from coral and algae to macroalgae dominance occurred over a short period of time.

Description of work: Field. Location: Caribbean. Keywords: Coral community, Bleaching, Storm damage, Disease, Macroalgae, Phase shift

Richardson, L. L. 1998. Coral diseases: What is really known? *Tree* **13**: 438-443.

This review investigates reports of emerging coral diseases over the past few years. The authors found that coral disease is increasing and contributing to reef degradation based on observations of diseased coral colony numbers. Recent studies describe the mechanisms of disease and are finally able to provide information helping to define the role of coral diseases. Topics include: the first coral diseases and early attempts at characterization; regional impacts of disease; disease emergence within the last 10 years; results of studies on individual diseases; the correlation between disease and environmental degradation; and prospects for the future. Overall, the continuation of research in this field is strongly encouraged.

Description of work: Review. Location: None. Keywords: Coral disease, Reef decline, Disease pathogen, Coral syndrome

Richardson, L. L., W. M. Goldberg, K. G. Kuta, R. B. Aronson, G. W. Smith, K. B. Ritchie, J. C. Halas, J. S. Feingold and S. L. Miller. 1998. Florida's mystery coral-killer identified. *Nature* **392**: 557-558.

A coral disease appeared on the Florida Reef Tract in June 1995. The pathogen responsible for the new disease was identified as a new species of *Sphingomonas*. Within 4 months of its discovery, the disease spread about 200 kilometers in the Florida Keys. The disease first targeted *Dichocoenia stokesi* with average mortality rates of 26% over an 11-week period. The number of diseased colonies was strongly correlated with the density of the colonies, regardless of depth, suggesting the disease is contagious. Following the outbreak, 16 other species of coral were affected. After 1995, outbreaks were recorded in 1996 and 1997, however the disease outbreaks were seasonal and occurred from June to October.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral, Disease, Bacteria, Pathogen, Outbreak

Roy, R. E. 2004. Akumal's reefs: Stony coral communities along the developing Mexican Caribbean coastline. *Revista de Biología Tropical* **52**: 869-881.

The conditions of stony corals in the Akumal-area of the Yucatan coastline are characterized at two depths along an inferred sedimentation gradient with respect to species composition, live cover, colony density, relative exposure to turf algal-sediment mats (TAS), and for one species (*Diploria strigosa*, Dana, 1848), tissue regression rates in the presence of TAS mats. Transect surveys were conducted and showed that live stony coral cover, density and relative peripheral exposure of colonies to TAS mats were inversely related to an inferred sediment stress gradient at 13 m. In 2000, live stony coral cover had decreased by 40-50% at two sites from 1990. Half of this loss occurred between 1998 and 2000 during an outbreak of white plague disease. Overall, fringing reefs near Akumal have declined significantly between 1997 and 2000.

Description of work: Field. Location: Caribbean. Keywords: Coral, Turf-algal sediment mats, Disease, Live cover

Ryan, J. C. 2001. The Caribbean gets dusted. *Bioscience* **51**: 334-338.

Caribbean corals and residents have long suffered from African dust. Previously, the impact of this dust focused on global impacts of heat and carbon cycles. However, recent research shows the possibility of impacts on the marine ecosystem and public health. This review addresses current evidence which indicates airborne pathogens and nutrients associated with African dust are troubling the marine ecosystems of the Caribbean.

Description of work: Review. Location: None. Keywords: Coral, Dust, Human health, Pathogens, Nutrients

Shinn, E. A., G. W. Smith, J. M. Prospero, P. Betzer, M. L. Hayes, V. H. Garrison and R. T. Barber. 2000. African dust and the demise of Caribbean coral reefs. *Geophysical Research Letters* **27**: 3029-3032.

It has been proposed that the huge transport of African dust across the Atlantic over the past 25 years has been a contributing factor to the decline of Caribbean coral reefs. Major coral bleaching events and reports of coral mortality coincide with years of maximum dust flux into the Caribbean. The elemental dust is comprised of iron, silicon, and aluminosilicate clays and also is the substrate for spores of soil fungus which has caused seafan disease in the Caribbean. The authors hypothesize that reef degradation is linked to the increase in dust transport and deposition. They propose future changes in the composition of African dust could not only affect coral reef organisms but possibly other ecosystems as well.

Description of work: Review. Location: Caribbean. Keywords: Coral, Dust, Disease, Bleaching, Mortality, Fungus, Nutrients

Sutherland, K. P., J. W. Porter and C. Torres. 2004. Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. *Marine Ecology Progress Series* **266**: 273-302.

This review discusses coral diseases, known etiologies, and efforts to determine unknown etiologies. Topics include: definitions of disease terms and how they relate to coral disease; the process of proving disease causation; alternate techniques for identifying disease-causing organisms, and a review of coral immunology.

Description of work: Review. Location: Caribbean and Indo-Pacific. Keywords: Coral Disease, Immunology, Coral stress

Williams, D. E. and M. W. Miller. 2005. Coral disease outbreak: Pattern, prevalence and transmission in *Acropora cervicornis*. *Marine Ecology Progress Series* **301**: 119-128.

A rapid progressing disease outbreak affecting *Acropora cervicornis* was observed in the Florida Keys, USA. At least 72% of tagged colonies were affected; live tissue cover of these colonies decreased from 96% to 12% and 28% of the colonies had complete mortality. Field experiments demonstrated the disease was transmissible by direct contact between affected and healthy coral and by the corallivorous snail *Coralliophila abbreviata*. This implies that the disease is biotic and the effective transmission suggests predation may exacerbate disease outbreaks in Caribbean

acroporid populations.

Description of work: Field. Location: Florida Keys. Keywords: Coral, Whiteband disease, Predation, Transmission, Mortality

Wilson, W. H., A. L. Dale, J. E. Davy and S. K. Davy. 2005. An enemy within? Observations of virus-like particles in reef corals. *Coral Reefs* **24**: 145-148.

Transmission electron microscopy (TEM) was used to examine stressed and non-stressed colonies of the scleractinian coral, *Pavona danai*, for the presence of virus-like particles (VLPs). Temperature shock and induction of latent viruses found in zooxanthellae was investigated. Overall findings were that the presence of VLPs are not a consequence of heat stress, but a temperature rise did appear to increase their abundance.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Viruses, Stress, Coral disease, Zooxanthellae, Coral health

### **Effects of Everglades Restoration**

Caccia, V. and J. Boyer. 2005. Spatial patterning of water quality in Biscayne Bay, Florida as a function of land use and water management. *Marine Pollution Bulletin* **50**: 1416-1429.

Twenty five stations across Biscayne Bay, FL were sampled monthly from January 1994-December 2003. Salinity, temperature, and dissolved oxygen were measured 10 cm below the surface and 10 cm above the bottom at each station. Laboratory analyses were conducted to determine total nitrogen (TN), total phosphorus (TP), total organic carbon (TOC), alkaline phosphatase activity (APA), and turbidity. There was a strong salinity gradient increasing from the coast to the open bay. Lower salinities were found in areas receiving freshwater input from canals and higher salinities were found near the ocean. There was a seasonal pattern for temperature within the Bay. Median temperature ranged from 26.1 C to 26.9 C. TN showed a strong increasing gradient from the coast to the open bay, with a median concentration ranging from 0.478 mg/l to 0.221 mg/l. No gradient was observed in TP with distance from land. TP measured at stations from the North Bay were significantly higher than other stations at all times of the year. Median concentrations of TP for the entire study area ranged from 0.009 mg/l to 0.005 mg/l. Seasonal differences were observed with respect to TP concentrations, especially at stations receiving freshwater input from canals. TOC had a strong increasing gradient from the coast to the open bay. Mean concentrations of TOC ranged from 4.67 mg/l to 2.75 mg/l. DO concentrations showed little variation with distance from land. DO median concentrations ranged from 6.9 mg/l to 6.2 mg/l. Like TP, turbidity was higher in the North Bay than at any other location, however the seasonal patterns differed at different locations. The authors concluded that the changes in water quality within different locations across Biscayne Bay are related to land use, and more specifically to the inputs of the canals coming through the Everglades. In general, stations near the coast were most affected by increased nutrient loads. The North Bay zone is heavily affected by freshwater input and turbidity from the Port of Miami and Munisport landfill.

Description of work: Field and Laboratory. Location: Biscayne Bay, Florida. Keywords: Everglades Restoration

Cooper, S., J. Huvane, P. Vaithyanathan and C. Richardson. 1999. Calibration of diatoms along a nutrient gradient in Florida Everglades Water Conservation Area-2A, USA. *Journal of Paleolimnology* **22**: 413-437.

Surface soil diatom assemblages were studied along various nutrient gradients in Everglades Water Conservation Area-2A (WCA-2A). The biggest shifts in species composition were observed along the phosphorus (P) gradient. Several species differences were also observed along carbon (C), nitrogen (N), calcium (Ca), and biogenic silica (BSi) gradients, although they were not as significant as those along the P gradient. The authors suggested that occurrence of *Nitzschia amphibia* and *Nitzschia palea* could be used as an indicators of high P values, while *Achnanthes miutissima* and *Mastogloia smithii* could be used as an indicators of low P. It was further suggested that all of these species may be useful as monitoring tools for eutrophication in projects like the Florida Everglades Restoration Plan.

Description of work: Field and Laboratory. Location: Everglades, FL. Keywords: Nutrient, Everglades Restoration, Diatom

Dodge, R. and K. Helmle. 2003. Past stony coral growth (extension) rates on reefs of Broward County, Florida: Possible relationships with Everglades drainage. Joint Conference of the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem, Palm Harbor, FL, April 13-18 1-5.

Annual growth rates, measured by linear extension, of stony coral were monitored for a 26 yr period in Broward County, FL. Specimens of *Montastraea faveolata*, and *Diploria labyrinthiformis* collected at two depths (9m and 18m) along a 30 mile north-south latitudinal gradient. These samples were sectioned and annual linear extension rates were determined. Corals collected from the southern portion of the study area at 9m depth had higher growth rates than those from the northern study site. Growth rates were also higher in all coral collected from 9m depth compared to those from 18m depth. When compared to environmental parameters it was found that coral growth rates were positively correlated with increasing salinity. There was no significant between linear extension rates and temperature. Based on these results, the authors suggested that increased freshwater discharge from the Everglades Restoration Project is likely to reduce salinity and coral growth rates.

Description of work: Field. Location: Broward County, Florida. Keywords: Everglades Restoration

Guardo, M. 1999. Hydrologic balance for a subtropical treatment wetland constructed for nutrient removal. *Ecological Engineering* **12**: 315-337.

The water budget was analyzed for the Everglades Nutrient Removal (ENR) project over a period of 732 days. The author determined that 86.2% of input flow came from inflow pumps, 11.2% from rainfall, and 2.6% from seepage from an adjacent area with a higher water table. The outflow was found to be 85.1% from the outflow pumps, 8.9% from evapotranspiration, and 6.0% from seepage of groundwater. The ENR project consists of exposing input waters to



natural and chemical processes in order to remove excess nutrients, especially phosphorus, before allowing the water to flow out into the rest of the Everglades. The author stated that the nutrient budget is closely related to the water budget because the influx and outflow of nutrients are mainly dependent on these hydrologic processes. The author also noted that different combinations of treatment processes are applied in different cells of the ENR project and that future research should focus on studying each cell independently.

Description of work: Field. Location: Florida Everglades. Keywords: Everglades Restoration

Juston, J. and T. DeBusk. 2005. Phosphorus mass load and outflow concentration relationships in stormwater treatment areas for Everglades restoration. *Ecological Engineering* 1-18.

Four stormwater treatment areas (STAs) in the Florida Everglades were observed to determine their effectiveness at removing phosphorus (P) by measuring P outflow. The STAs had either emergent aquatic vegetation (EAV), or submerged aquatic vegetation (SAV). Prior land use was also a factor. The STAs had previously been either recently farmed (RF) land, or historic wetland (HW). It was found that SAV provided better P removal than EAV, and that EAV-HW systems were better than EAV-RF systems. In general, SAV and EAV-HW systems had outflows with P concentrations below 20ug/l. These systems also demonstrated an ability to buffer small to moderate pulses in P loading.

Description of work: Field. Location: Florida Everglades. Keywords: Everglades Restoration

Lirman, D., B. Orlando, S. Maciá, D. Manzello, L. Kaufman, P. Biber and T. Jones. 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: Diversity, abundance, distribution, and environmental correlates. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**: 121-135.

The hardbottom habitat of Biscayne Bay make it a marginal environment for coral growth. An assessment of the Bay was performed to evaluate the coral populations present and investigate the factors that limit coral abundance, diversity, and distribution. Considering future changes in freshwater delivery into Biscayne Bay, due to the Everglades restoration, would affect salinity patterns and increase sediment loads which in turn are important to the abundance and distribution of corals in the area. Biscayne Bay contains a limited number of coral species. The physical characteristics of the basin make it a marginal environment for coral growth so the presence of *Siderastrea radians* and *Porites furcata* in Biscayne Bay indicate that these species are able to tolerate fluctuating conditions. Three factors, temperature, sedimentation, and salinity appeared to limit coral abundance, diversity and distribution in the bay. Sediment burial was shown experimentally to influence growth and mortality of *S. radians*. The salinity of the bay is influenced by freshwater inputs from canal, sheetflow, and groundwater sources that create a low mean salinity near-shore environment with large salinity fluctuation. Chronic exposure to low salinity was shown experimentally to decrease the growth of *S. radians*. The location of Biscayne Bay, downstream of the Everglades watershed, highlights the need to understand the relationship between the physical environment and the benthic community health.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral community, South Florida, Salinity, Sedimentation, Temperature, Hardbottom habitat, Everglades restoration

Noe, G., D. Childers and R. Jones. 2001. Phosphorus Biogeochemistry and the Impact of Phosphorus Enrichment: Why is the Everglades so Unique? *Ecosystems* **4**: 603-624.

This article reviews research on phosphorus (P) biogeochemistry with respect to the Everglades Restoration Project. The authors note that the Florida Everglades is oligotrophic and P limited with high nitrogen to phosphorus ratios and is consequently extremely sensitive to even small increases in P. Geology, hydrology, and oxidative microbial nutrient cycling are stated as the causes of P limitation in the Everglades.

Description of work: Review. Location: Everglades, FL. Keywords: Everglades Restoration, P,N

Rudnick, D., D. Childers, J. Boyer and T. Fontaine. 1999. Phosphorus and nitrogen inputs to Florida Bay: The importance of the Everglades watershed. *Estuaries* **22**: 398-416.

Annual inputs of water, total phosphorus (P), total nitrogen (N), and dissolved inorganic nitrogen (DIN) were calculated for the Everglades National Park (ENP). Changes in nutrient concentrations out of ENP into Florida Bay were also examined. Water flowing into ENP was generally high in total N and low in total P. All the total P and DIN flowing into ENP was rapidly removed from the water, creating very high N:P ratios which exceeded 400 in some places. Effects of Everglades Restoration on Florida Bay could not be determined in this study. The authors suggest that studies be carried out regarding interaction of freshwater released from the Everglades and the mangrove zone which lies between there and the Florida Bay. They suggested that increased freshwater flow is likely to decrease salinity in the mangrove zone, thereby decreasing its ability to act as a sink for nutrients coming out of ENP.

Description of work: Field. Location: Florida Everglades. Keywords: Everglades Restoration

Schaffranek, R. 1999. Hydrologic studies in support of South Florida ecosystem restoration. Annual Water Resources Planning and Management Conference, June 6-9, 1999 Tempe, AZ 1-9.

Hydraulic and hydrologic measurements were used to create a model to study the southern part of the Everglades. Flow, flow velocity, nutrient loads, mass flux, and vegetative effects on water movement were taken into account, as well as evapotranspiration, wind, groundwater exchange, and canal interactions. These findings are being incorporated into a single model to test and evaluate various restoration scenarios.

Description of work: Laboratory. Location: Everglades, FL. Keywords: Everglades Restoration, Hydrology, Hydraulic

Wang, J. D., J. Luo and J. S. Ault. 2003. Flows, salinity, and some implications for larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science* **72**: 695-723.

Data on tides, wind and freshwater inflows were combined with physical and biological performance tests to develop a numerical model. The model was used to predict currents, residence times, salinity patterns and shrimp larval transport in S. Florida. Model predictions regarding tidal currents were found to be within 0.01 m/s of the observed values. Direct currents

are controlled by tide while sub tidal currents are controlled by wind. Sub tidal currents were found to have a large effect on residence times. Model predictions of salinity and currents correlated well with data observations. The authors suggested that the model could be used to estimate spatial shrimp population dynamics, making it useful for ecological risk assessment with regards to water management, Everglades restoration, and climate change.

Description of work: Field and Laboratory. Location: Biscayne Bay, Florida. Keywords: Inlet, Hydrodynamics, Salinity, Currents, Larval transport, Water management, SGD, Everglades Restoration

Weaver, K. and G. Payne. 2004. Status of water quality in the Everglades protection area. Everglades Consolidated Report 2004 1-19.

A review of water quality standards for the Everglades protection area (EPA) for 2003. Dissolved oxygen was considered a concern since it was frequently measured at concentrations below 5.0 mg/l which is the criteria set by the Florida Administrative Code. There has been an alternate criteria proposed on a site-specific bases because this area is naturally low in dissolved oxygen. Fifteen pesticides were detected in the EPA, these included atrazine, chlorpyrifos ethyl, and diazinon among others. The Everglades Forever Act (EFA) has designated a criterion for total phosphorus (P) of 10 ug/l, although this had not been made a requirement at the time of this review. Total P ranged from 4.6 ug/l to 14.8 ug/l and exhibited a decreasing north to south gradient. The authors suggest that this trend is due to increased P input from runoff near the agricultural area in the north. Total nitrogen (N) concentrations ranged from 0.8 ug/l to 2.2 ug/l. Total N exhibited a decreasing north to south gradient similar to total P. The authors suggested this was also due to increased input near the agricultural zone.

Description of work: Review. Location: Florida Everglades. Keywords: Everglades Restoration

### **Heavy Metals**

Bastidas, C. and E. Garcia. 1999. Metal content on the reef coral *Porites astreoides*: and evaluation of river influence and 35 years of chronology. Marine Pollution Bulletin **38**: 899-907.

Metal contents in *Porites astreoides* from two experimental sites were compared for ten metals (Al, Ca, Cd, Cu, Cr, Fe, Hg, Pb, V, and Zn). The concentrations of most of the metals were significantly higher at both experimental sites than reported "pristine" values for the Caribbean. Corals from the experimental site closest to the river inputs had higher concentrations of Al and Fe, while corals from the site furthest from the river inputs had a higher concentration of Cr, but this was only noted in one colony. Corals from this second site also had increased levels of Ca, but this was discounted due to differing growth rates between the two sites. The authors suggest that the time period studied (35 yrs) was too short to display the shift from pristine to current conditions, and that analysis of *P. astreoides* indicates pollution exposure to the experimental locations for at least the past 35 yrs.

Description of work: Field and Laboratory. Location: Caribbean. Keywords: Coral, Heavy metal

Bastidas, C. and E. M. Garcia. 2004. Sublethal effects of mercury and its distribution in the coral *Porites asteroides*. Marine Ecology Progress Series **267**: 133-143.

Semi-static, chronic bioassays using HgCl<sub>2</sub> were conducted on specimens of *Porites asteroides* collected from Bajo Caiman, Venezuela. These experiments examined the concentration of Hg in adult coral colonies; the distribution of Hg throughout three coral compartments (polyps, zooxanthellae and skeleton); and the sublethal effects of Hg on *P. asteroides*. Hg concentration in the water was variable due to natural losses and the pulsed doses given during the assays. Concentrations of Hg in the coral as a whole as well as those in zooxanthellae and the skeleton were directly related to water concentrations, but Hg concentration in polyps was not. These results supported the hypothesis that coral polyps may have actively diverted Hg to other coral compartments as a method of detoxification. Absolute Hg concentration values (per unit surface area) were highest in the zooxanthellae, followed by polyps, and then the skeleton.

Description of work: Laboratory. Location: Caribbean. Keywords: Mercury, Bio concentration, Coral, Detoxification, Heavy Metal

Brown, B. E. and M. C. Holley. 1982. Metal levels associated with tin dredging and smelting and their effect upon intertidal reef flats at Ko Phuket, Thailand. Coral Reefs **1**: 131-137.

This study provided baseline data for heavy metal concentrations in tropical marine waters adjacent to a tin smelting operation. The concentration of heavy metals was determined for invertebrate, bivalve, algal and coral species, as well as for water and sediment. This data was compared between species and against water and sediment heavy metal concentration values. Results of the analysis showed high levels of heavy metals in the sediment and bivalves at the site closest to the tin smelter. However, corals at this site did not contain elevated metal concentrations compared to corals from unpolluted areas. The authors had four possible explanations for this: 1) the form of metals in the system may not be biologically available; 2) intertidal corals may be conditioned to adapt to stress; 3) the presence of calcium may have reduced the toxicity and absorption of heavy metals; 4) corals may have reduced internal heavy metal concentrations with improved metal storage or regulation.

Description of work: Field. Location: Indo-Pacific. Keywords: Heavy metal, Coral, Tin smelting

Burnett, W. C., H. Bokuniewicz, M. Huettel, W. S. Moore and M. Taniguchi. 2003.

Groundwater and pore water inputs to the coastal zone. Biogeochemistry. **66**: 3-33.

This paper reviews submarine groundwater discharge (SGD) studies done from 1993 through 2003. The authors defined the process of submarine groundwater discharge and reviewed global flux estimates and biogeochemical consequences. SGD is defined as "any and all flow of water on continental margins from the seabed to the coastal ocean regardless of fluid composition or driving force." Three general approaches to assessing SGD were reviewed; these included modeling, physical measurement, and tracer techniques. Past groundwater flux estimates were usually calculated by making a number of assumptions and resulted in large uncertainty values. There is very little data available on the magnitude of SGD flow and exchange in coastal sediments. The authors suggest that new technology, and modeling strategies need to be

developed in order to estimate fluxes and differentiate between the factors that influence SGD.

Description of work: Review. Location: USA. Keywords: Heavy metal, Coral, SGD, Coastal upwelling.

David, C. P. 2002. Tracing a mine tailings spill using heavy metal concentrations in coral growth bands: Preliminary results and interpretation. Proceedings of the 9<sup>th</sup> International Coral Reef Symposium, 2000 **2**: 1213-1218.

Growth bands from *Porites* skeletons were examined to recreate a chronological record of exposure to varying metal concentrations. Samples were collected from three reefs with increasing distance from a mine spill. Samples from the reef closest to the spill showed a spike in Cu levels in the 1996-1997 growth bands. These years corresponded with the mine spill that occurred in early 1996. Data from the samples collected at the next closest reef also showed a spike in Cu levels although not as pronounced. This may be due to the high baseline Cu values that persisted at this site. Samples from the reef furthest from the spill showed no increase in Cu levels in the 1996-1997 growth bands.

Description of work: Field. Location: Bali, Indonesia. Keywords: Heavy metal, Coral, Growth bands, Copper

Denton, G. R. W. and C. Burdon-Jones. 1986. Trace metals in corals from the Great Barrier Reef. Marine Pollution Bulletin **5**: 209-213.

Octocorals and scleractinian corals were analyzed for concentrations of Zn, Cu, Cd, Ni, and Pb. Octocorals had a greater affinity for Zn, Cu, and Cd than scleractinian corals and had higher concentrations of all metals. The data supported the theory that *Sarcophyton* sp. is a good indicator of trace metal concentrations. Species identification was the main disadvantage to using octocorals as biomonitors of heavy metals in the environment.

Description of work: Field. Location: Australia. Keywords: Heavy metal, Coral, Bioindicators

Dodge, R. E. and T. R. Gilbert. 1984. Chronology of lead pollution in banded coral skeletons. Marine Biology **82**: 9-13.

This study found that annual skeletal growth bands of reef building corals contain a record of lead pollution in the marine environment. The Pb/Ca ratio in dated coral samples were examined. An accurate timeline of Pb pollution was developed, showing an increase in concentrations from 1954 -1980. This study demonstrates the potential for using coral skeletons as historical records of Pb concentrations in marine systems.

Description of work: Laboratory. Location: Caribbean. Keywords: Heavy metal, Coral, Growth bands, Pb, Ca

Edinger, E. N., J. Jompa, G. V. Limmon, W. Widjatmoko and M. J. Risk. 1998. Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time. *Marine Pollution Bulletin* **36**: 617-630.

Transect surveys were taken on 15 reefs in three regions of Indonesia to estimate the relative decrease of coral species diversity associated with reef degradation. The type of degradation investigated was land-based pollution (sewage, sedimentation, and/or industrial pollution). Reefs subject to these stresses showed 30-50% reduced diversity at 3 m depth and 40-60% reduced diversity at 10 m depth relative to unpolluted reefs in each region. Physically damaged reefs (bombed or anchors) were ~ 50% less diverse at 3 m than undamaged reefs at the same depth. At 10 m depth the relative decrease in diversity due to physically damaged reefs was 10%.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Reef degradation, Biodiversity, Land-based pollution, Nutrient, Heavy Metal

Esslemont, G. 2000. Heavy metals in seawater, marine sediments and corals from the Townsville section, Great Barrier Reef Marine Park, Queensland. *Marine Chemistry* **71**: 215-231.

Heavy metal concentrations were measured in seawater, marine sediments and corals from the Townsville section of the Great Barrier Reef Marine Park. Seawater concentrations of all metals except lead and copper were within Australian and New Zealand Environment and Conservation Counsel (ANZECC) guidelines. Lead, copper and zinc were significantly higher in sediments than other metals. Concentrations of nickel and chromium were also higher but in relatively stable and nonreactive forms. There were higher concentrations of metals in coral tissues than in coral skeletons, although this varied by species. The authors recommend using coral skeletons rather than tissues to monitor heavy metal concentrations because they mirror environmental conditions more closely.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Heavy metal, Copper, Temperature

Esslemont, G., V. J. Harriott and D. M. McConchie. 2000. Variability of trace-metal concentrations within and between colonies of *Pocillopora damicornis*. *Marine Pollution Bulletin* **40**: 637-642.

Concentrations of heavy metals (Cd, Pb, Cu, Ni, Cr) were measured in *Pocillopora damicornis* tissue and skeleton. The samples were collected from a pristine area of Australia and were assumed to contain ambient levels of heavy metals. This study identified trends in the partitioning of different metals between coral tissue and skeleton in *P. damicornis*. There were also intra-colony and inter-colony differences in absolute concentrations. Minimum sample sizes were also reported for achieving 95% confidence limits in data obtained from flame atomic adsorption spectrophotometry (AAS). The ratios of metal concentrations in tissues to the concentrations in skeletal material was ranked (from high-to-low): Cd, Pb, Cr, Cu, Ni. The authors concluded that the use of coral tissue for heavy-metal bio-assays was not realistic

because of the amount of coral that had to be harvested to obtain statistically accurate results. Coral skeleton is suggested as an appropriate material because numerous samples can be taken with little damage to the coral colony.

Description of work: Field. Location: Australia. Keywords: Coral, Heavy metal

Fichez, R., M. Adjero, U. Bozec, L. Breau, Y. Chancerelle, C. Chevillon, P. Douillet, J. Fernandez, P. Frouin, M. Kulbicki, B. Moreton, S. Ouillon, C. Payri, J. Perez, P. Sasal and J. Thebault. 2005. A review of selected indicators of particle, nutrient and metal inputs in coral reef lagoon systems. *Aquatic Living Resources* **18**: 125-147.

This paper is a review of the literature on indicators of several types of pollution to coral reefs, including particles, nutrients, and metals. The authors suggest that bioindicators be used in conjunction with abiotic indicators in order to more accurately predict the environmental response to inputs of particles, nutrients, and metals. They also suggest that these indicators be "calibrated" to each local system to provide more efficient environmental monitoring tools. This review illustrates a critical information gap in that there is very little scientific background regarding environmental indicators in tropical systems compared to temperate ones.

Description of work: Review. Location: None. Keywords: Coral, Eutrophication, Heavy metal, Nutrient, Sediment

Fisher, L. E. 1980. Annual update: Environmental assessment of the Broward County North Regional Outfall. 15 pp.

This annual update was done to determine if the presence of the North Broward (Pompano) outfall and its discharge has had any effect on the physical conditions of the surrounding environment. The Pompano outfall terminus is located 2.377 km offshore just south of the Hillsboro Inlet at a depth of 35 m. The "third reef" is 150 m west of the outfall terminus in 30 m of water and rises to 15 m over a distance of 100 m. Analysis of grain size distribution was done to determine if bottom sediment consistency has remained the unchanged. Sediment analysis was performed to look for the presence of selected trace metals, pesticides, and PCB's attributed to the discharge. Results of the grain size distribution analysis showed no significant difference between the control site and the outfall site. The chemical analysis of bottom sediments showed no pesticides or PCB's above the detection limits. Comparison of chemical analyses of the present study with one performed in 1978-79 shows slight increases for cadmium, chromium, lead, zinc, and nickel with no change or decreases for copper, iron and all chlorinated hydrocarbons. Chromium showed a significant decrease at the terminus of the outfall, lead at the terminus is twice the amount of other sites, and nickel shows a high concentration at the easternmost and deepest site. Overall, no changes have occurred in the consistency of bottom sediments between control and outfall samples. Differences (positive or negative) observed for the trace metals, pesticides, and PCB's may or may not be real; the variability may occur naturally in the sediment. No visual changes in the outfall environment were observed.

Description of work: Field and Laboratory. Location: Pompano, Florida. Keywords: Pompano Outfall, Sediment, Pesticide, PCB, Trace metal, Cadmium, Chromium, Lead, Zinc, Nickel, Copper, Iron

Flammang, P., M. Warnau, A. Temara, D. J. W. Lane and M. Jangoux. 1997. Heavy metals in *Diadema setosum* (Echinodermata, Echinoidea) from Singapore coral reefs. *Journal of Sea Research* **38**: 35-45.

This study determined the distribution of heavy metal contamination on eight coral reefs in the Southern Islands, Singapore. The distributions of Zn, Pb, Cd, Fe, Cr, Cu and Ti were mapped using data taken from *Diadema setosum* and sediment samples. The usefulness of *D. setosum* as a biomarker species was evaluated by comparing metal concentrations in the echinoid to those in the water column and sediment. The differences in metal concentrations between three body compartments, (gonads, spines and skeleton) were analyzed for any trends. All metals were selectively distributed among the body compartments but there was no obvious correlation with environmental concentrations. A trend of decreased metal concentrations was found with increased distance from Singapore.

Description of work: Field. Location: Indo-Pacific. Keywords: Heavy metal, Coral

Gilbert, A. and H. Guzman. 2001. Bioindication potential of carbonic anhydrase activity in anemones and corals. *Marine Pollution Bulletin* **42**: 742-744.

Carbonic Anhydrase (CA) activity levels were assessed in two sea anemones, *Condylactis gigantea* and *Stichodactyla helianthus*, and one species of coral, *Montastraea cavernosa*. Field studies were conducted at pristine control sites and polluted sites (for coral and anemones), lab exposure to heavy metals was done for anemones only. CA activity levels decreased in both species of anemones as metal concentrations increased. CA activity levels were also significantly decreased in coral colonies and anemones from the polluted sites compared to the control sites. The authors note that decreased activity levels were detected in anemones in response to metal exposure without instances of coral bleaching and postulate that monitoring CA activity levels may be a more sensitive measure of stress.

Description of work: Field and Laboratory. Location: Caribbean. Keywords: Coral, Heavy metal, Carbonic anhydrase

Glynn, P. W., A. M. Szmant, E. F. Corcoran and S. V. Cofer-Shabica. 1989. Condition of coral reef cnidarians from the northern Florida reef tract: Pesticides, heavy metals, and histopathological examination. *Marine Pollution Bulletin* **20**: 568-576.

This study compared two coral reefs in Biscayne National Park. Each reef contained Scleractinian coral and octocoral assemblages. Abundance, field condition, concentrations of pesticides and heavy metals, and histopathological condition were determined for both communities. It was hypothesized that the coral reef closest to the input of urban pollution would be more degraded than the one further from the source. No significant differences were found between the two coral reef communities. Reef degradation, indicated by blemishes, abnormalities, bleached and dead tissue, and invading pathogens were found on both reefs. Organochlorine pesticides and heavy metals were also found at high but relatively equal



concentrations in samples from both reefs.

Description of work: Field. Laboratory. Location: Florida. Keywords: Pesticide, Coral, Heavy metal, Herbicide

Guzman, H. and C. Jimenez. 1992. Contamination of coral reefs by heavy metals along the Caribbean coast of Central America. *Marine Pollution Bulletin* **24**: 554-561.

*Siderastrea siderea* were surveyed along 23 reef tracts to determine concentrations of 12 different heavy metals (Al, V, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, Sn, and Ba). Sn and Ba were not detected at any of the sites, however methods used would not have detected these metals in small quantities. No pattern was found with metal concentrations between study sites. Most metals were detected at all sites, even those sites deemed to be "pristine" although in lower concentrations. Al, Fe, and Mn were detected in the highest concentrations in both sediments and coral skeletons. Possible sources of metals in this area include; discharge by oil tankers, antifouling paints, oil spills, fertilizers, lime, and pesticides.

Description of work: Field. Location: Caribbean. Keywords: Coral, Heavy metal, Pesticide

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Harland, A. D. and B. E. Brown. 1989. Metal tolerances in the scleractinian coral *Porites lutea*. *Marine Pollution Bulletin* **20**: 353-357.

The effects of elevated levels of Fe on *Porites lutea* were tested. Samples of coral were collected

from a site polluted with tin smelter effluent and from a control site. Effects of exposure to various Fe concentrations were determined by measuring zooxanthellae loss. Corals from the control site showed a marked decrease in symbiont concentration when exposed to elevated concentrations of Fe compared to the corals from the polluted site. Results suggested that some coral species have developed a tolerance to elevated metal concentrations.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Coral, Heavy metal, Iron

Howard, L. and B. Brown. 1987. Metals in *Pocillopora damicornis* exposed to tin smelter effluent. *Marine Pollution Bulletin* **18**: 451-454.

Metal concentrations were measured in tissues and skeletons of *Pocillopora damicornis* from an intertidal reef near a tin smelting operation. Tissues from colonies near the tin smelting operation had significantly higher concentrations of ten metals compared to controls. The authors suggest that the most likely source of this metal contamination is effluent solution from the tin smelter being discharged into waters near the reef. Coral skeleton samples near the smelter showed no significant increase in metal content compared to control samples. Significantly reduced growth rates, measured by linear extension and CaCO<sub>3</sub> accumulation, were also observed in colonies near the smelter. The authors suggest that higher metal concentrations inhibit chitin synthetase, the enzyme used for calcification by *P. damicornis*.

Description of work: Field and Laboratory. Location: Asian Pacific. Keywords: Coral, Heavy metal

Howard, L. S. and B. E. Brown. 1984. Heavy metals and reef corals. *Oceanogr. Mar. Biol. Ann. Rev.* **22**: 195-210.

The authors reviewed the literature available on heavy metal inclusion into coral reefs. Possible sources of metal pollution included mining and dredge operations, smelting processes, offshore drilling operations, and discharge from sewage plants and desalinization processes. The authors suggest that heavy metals are being incorporated into corals through feeding, and that this uptake and deposition into coral skeletal tissues may be compromising the integrity of the coral structure, making the coral more susceptible to mechanical damage by storms etc. The authors also identified a major information gap in that there are few studies on the effects of metals on coral reefs, and those that are available seem to focus on reefs as bioindicators.

Description of work: Review. Location: None. Keywords: Heavy metal, Coral, Skeletal inclusion

Howard, L. S. and B. E. Brown. 1986. Metals in tissues and skeleton of *Fungia fungites* from Phuket, Thailand. *Marine Pollution Bulletin* **17**: 569-570.

Samples of *Fungia fungites* and *Pocillopora damicornis* were collected from one polluted site and two control sites. Metal concentrations in tissue and skeletal material were measured. The two coral species had different metal concentrations in their tissues but similar concentrations in the skeletal material. *F. fungites* did not exhibit higher metal concentrations at the polluted site

where as *P. damicornis* did. The authors suggested that skeletal material did not provide an accurate record of metal concentrations in the environment.

Description of work: Field. Location: Indo-Pacific. Keywords: Heavy metal, Coral

Macauley, J. M., J. K. Summers, V. D. Engle and L. C. Harwell. 2002. The ecological condition of South Florida estuaries. *Environmental Monitoring and Assessment* **75**: 253-269.

The ecological condition of South Florida estuaries was assessed based on regional monitoring during the summer of 1995. Samples were collected and measurements made on water and sediment quality, benthos, and fish tissue contaminants. Findings showed elevated concentrations of metals and pesticides in sediments and fish tissue with some levels exceeding guidance values. Dissolved oxygen levels of the bottom over 23-37% of the area were below state criteria. The study area spanned Anclote Key to the mouth of the Indian River. Based on a calculated index of ecological condition, 9% of the area exhibited degraded biology and impaired use.

Description of work: Field. Location: East coast, South Florida. Keywords: Inlet, Ecological condition, Environmental assessment, Water quality, Sediment, Benthos, Fish tissue, Metals, Pesticides, Oxygen

Mokhtar, M., A. Khalik, B. Wood, C. Hou-Weng, T. Ling and A. Sinniah. 2002. Trace metals in selected corals of Malaysia. *Journal of Biological Sciences* **2**: 805-809.

Concentrations of mercury, manganese, zinc and chromium were compared in *Porites* and *Favia* species of coral from Tioman, Labuan, Tanjung Aru and Teluk Sepangar using neutron activation analysis. Zinc concentrations were highest in both species of coral from Tanjung Aru followed by Teluk Sepangar, Labuan and then Tioman. The authors note that Tioman is an island that has been declared a marine park where environmental protection laws are much more strict, and that Tanjung Aru and Teluk Sepangar are located near shorelines of a large city. Mean concentrations of manganese in both corals were highest at Labuan. Chromium and mercury levels in both coral species from all locations were relatively low, and in some situations completely below detectable levels.

Description of work: Field and Laboratory. Location: Asian-Pacific. Keywords: Coral, Heavy metal, Chromium, Manganese, Mercury, Zinc

Negri, A. and A. Heyward. 2001. Inhibition of coral fertilisation and larval metamorphosis by tributyltin and copper. *Marine Environmental Research* **51**: 17-27.

Copper (Cu) and tributyltin (TBT) are found in antifouling paints. This study tested the effects of these two substances on fertilization success and larval metamorphosis in *Acropora millepora*. Cu inhibited fertilization in 50% of *A. millepora* gametes at concentrations of 17.4 ug/l ( $\pm 1.1$ ). TBT inhibited fertilization in 50% of *A. millepora* gametes at concentrations of 200 ug/l ( $\pm 31$ ). Cu inhibited metamorphosis in 50% of *A. millepora* larvae at concentrations of 110 ug/l ( $\pm 20$ ). TBT inhibited metamorphosis in 50% of *A. millepora* larvae at concentrations of 2.0 ug/l ( $\pm 0.3$ ).

Antifouling paints which contained a mixture of TBT and Cu inhibited fertilization and metamorphosis of *A. millepora* by 100%. Both TBT and Cu had toxic effects at nominal concentrations close to those set by EPA guidelines. The authors concluded that coral fertilization and metamorphosis is negatively affected by both TBT and Cu. The authors also suggest that more research be done to assess the impacts of these and other compounds on reef building corals in order to better monitor and regulate their usage in antifouling paints. Description of work: Laboratory. Location: Australia. Keywords: Herbicide, Pesticide, Heavy metal, Coral

Nystrom, M., I. Nordemar and M. Tedengren. 2001. Simultaneous and sequential stress from increased temperature and copper on the metabolism of the hermatypic coral *Porites cylindrica*. *Marine Biology* **138**: 1225-1231.

Stress responses from *Porites cylindrica* were measured after 24 hour exposure to copper ( $11 \mu\text{g l}^{-1}$ ), increased temperature ( $+4^\circ\text{C}$ ), and a combination of these. Responses were also measured from colonies that were exposed to increased temperature for 24 hours, allowed to recover for 5 days, and then exposed to copper for 24 hours. Changes in gross primary production and respiration were measured. There was a significant reduction in primary production and respiration in response to elevated temperature and combination of elevated temperature with exposure to copper, exposure to copper alone caused a decrease in respiration but not in primary production. Corals that were exposed to increased temperature and allowed to recover for 5 days before exposure to copper had significantly reduced primary production but no significant impact was observed on respiration. These results indicated that some stressors may affect corals in combinations more profoundly than in isolation.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Coral, Heavy metal, Copper, Temperature

Peters, E. C., N. J. Gassman, J. C. Fireman, R. H. Richmond and E. A. Power. 1997. Eco toxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* **16**: 12-40.

Information gaps related to the effects of chemical contaminants on tropical marine ecosystems were evaluated. Heavy metals, petroleum, and synthetic organics were discussed in the context of ecosystem management and ecological risk assessment. Some of the most important sources of pollutants are terrestrial runoff, sewage outfalls, desalination plants, landfills, oil refineries and tanker spills. Coral colonies can be affected by all of these. Exposure to heavy metals causes production of mucus and expulsion of symbiotes as a means of excretion, reduced growth rate and species diversity also occur in reefs exposed to metals. Research suggests that small scale chronic oil spills may be more toxic than single large scale spills. Dispersants in combination with oil also increased tissue death and bleaching events in corals. Studies show increasing levels of pesticides, particularly lindane, DDT, and chlordane in nearly 100% of corals in the Great Barrier Reef and reefs off the Florida Keys. In general, data on pollutants and biological responses is much more complete for temperate marine and freshwater systems. It has not yet been established if the fate and transport of pollutants in tropical marine systems is similar to that of temperate systems. Most monitoring programs in tropical systems quantified

ecological responses but provided limited data on the stressors. Data on toxic pollutant levels that caused adverse effects in the field are limited. The author suggests that studies need to be done where contaminant levels in the water, sediment, and organisms are all measured at the same time in the same locations, and that researchers need to use the latest technology and appropriate identification protocols to produce more accurate results.

Description of work: Review. Location: None. Keywords: Coral, Heavy metal, Pharmaceutical, Organic, Pesticide, Herbicide

Ramos, A. A., Y. Inoue and S. Ohde. 2004. Metal contents in *Porites* corals: Anthropogenic input of river run -off into a coral reef from an urbanized area, Okinawa. *Marine Pollution Bulletin* **48**: 281-294.

This study provided additional data on metal pollution as validation of a diffusion model previously developed for this area. The goal of this study was to better understand the effects of anthropogenic activity on the distribution of metals in coastal environments. Analysis of river and seawater samples were used to establish normal background values of various metals. Results of the study revealed high levels of Mn, Zn, Ag and Pb in *Porites* coral skeleton compared to samples from the control site.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Heavy metal, Manganese, Lead

Rees, J., D. Setiapermana, V. Sharp, J. Weeks and T. Williams. 1999. Evaluation of the impacts of land-based contaminants on the benthic faunas of Jakarta Bay, Indonesia. *Oceanologica ACTA* **22**: 627-640.

Concentrations of Pb, Cu, Zn, Cr, and Ni were measured in seawater, suspended particulate matter (SPM) and sediments, as well as in coral tissues of *Goniopora lobata* and *Lobophyllia hemprichii* along a 72 km transect. Metal concentrations in seawater and SPM showed similar trends throughout the study transect with the highest concentrations being offshore. All metals in the sediments increased from offshore to inshore. The authors suggest that these results indicate a distribution controlled by seasonal hydrodynamics rather than spatial proximity to a pollution source. Very few measurements of metal concentrations in coral tissues were made because of sparse or very poor coral community structure. Those that were sampled showed no significant concentration differences between samples, but trends followed those of metal concentrations in seawater and SPM. However, coral cover and diversity increased significantly at 2 m sampling depth from inshore to offshore, suggesting that corals near shore are more stressed than those offshore. The authors suggest that the near shore corals were stressed by nutrient or organic pollutants, and not by heavy metals. Metal concentrations in offshore corals reflect seasonal fluctuations in dissolved metal in seawater.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Sediment, Heavy metal, Nutrient

Reichelt-Brushett, A. and P. Harrison. 2000. The effect of copper on the settlement success of larvae from the scleractinian coral *Acropora tenuis*. *Marine Pollution Bulletin* **41**: 385-

The effect of copper on the settlement success of larvae from *Acropora tenuis* was observed. Larval colonies of *A. tenuis* were exposed to different concentrations of copper for a 48 hour period. The authors found that concentrations of 20  $\mu\text{g l}^{-1}$  and less had no significant effect on larval settlement. Concentrations of 42 and 81  $\mu\text{g l}^{-1}$  significantly reduced settlement success, and at concentrations of 200  $\mu\text{g l}^{-1}$  all larvae died. They calculated the  $\text{EC}_{50}$  values (value where half of the colonies were effected) to be 35  $\mu\text{g l}^{-1}$ .

Description of work: Field. Location: Australia. Keywords: Coral, Copper, Heavy metal

Reichelt-Brushett, A. J. and P. L. Harrison. 1999. The effect of copper, zinc and cadmium on fertilization success of gametes from scleractinian reef corals. *Marine Pollution Bulletin* **38**: 182-187.

Bioassays testing the effects of Cu, Zn and Cd on gamete fertilization were conducted using the coral, *Goniastrea aspera*. Coral gametes were most affected by the Cu treatments. Fertilization success dropped to 41% at a Cu concentration of 20  $\mu\text{g/l}$ . Zn and Cd had little effect with significant reductions in fertilization success occurring at 500  $\mu\text{g/l}$  and 200  $\mu\text{g/l}$  respectively.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Heavy metal

Reichelt-Brushett, A. J. and G. McOrist. 2003. Trace metals in the living and nonliving components of scleractinian corals. *Marine Pollution Bulletin* **46**: 1573-1582.

Trace metal concentrations in the skeleton, tissue and zooxanthellae of *Acropora tenuis* were analyzed. The separation and analysis method used was very effective for obtaining accurate measurements of trace metals in different coral compartments. Zooxanthellae had the highest concentration for most metals (Al, Fe, As, Mn, Ni, Cu, Zn, Cd, Pb). The exact process by which trace metals are transferred from symbionts to coral tissue is unclear. The authors recommend that metal concentrations in zooxanthellae be considered in future studies involving corals as biomonitors of metal pollution. Gamete and mucus production were thought to play an important role in the distribution of metals in corals and should also be considered when determining metal load.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Heavy metal

Reichelt - Brushett, A. J. and P. Harrison. 2005a. The effect of selected trace metals on the fertilization success of several scleractinian coral species. *Coral Reefs* **24**: 524-534.

The effects of selected trace metals; copper, lead, zinc, cadmium, and nickel, on fertilization success of several scleractinian corals were tested. In general, all these metals had a significant effect on fertilization success, to varying degrees, with copper being the most toxic, followed by lead, zinc, cadmium, and then nickel. The  $\text{EC}_{50}$  (concentration that reduces fertilization rate by 50% relative to a control group) for copper was between 15 and 40  $\mu\text{g l}^{-1}$ , depending on species. The  $\text{EC}_{50}$  values for lead were two orders of magnitude higher than this, and the  $\text{EC}_{50}$  values

for the other metals could not be determined. The authors suggest that much more care should be taken to limit the input of all trace metals into reef waters to avoid reduced fertilization success.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Heavy metal, Fertilization

Reichelt - Brushett, A. J. and K. Michalek-Wagner. 2005b. Effects of copper on the fertilization success of the soft coral *Lobophytum compactum*. *Aquatic Toxicology* **74**: 280-284.

The effects of various concentrations of copper on the fertilization success of the soft coral *Lobophytum compactum* were assessed in two experiments. In the first experiment twenty male and female colonies of *L. compactum* were collected from the Great Barrier Reef (GBR) intertidal zone 10 days prior to spawning and exposed to treatments of copper in concentrations of 6, 9, 16, 22, 36, 69, and 132  $\mu\text{g l}^{-1}$ . Fertilization success was 90% in the control group and 68% in the experimental group at the highest copper concentration. The experimental group had significantly lower fertilization success at concentrations above 69  $\mu\text{g l}^{-1}$ . In the second experiment the copper concentrations were 18, 25, 39, 69, 117, 489, and 676  $\mu\text{g l}^{-1}$ . The control group had a fertilization success rate of 82%; a significant difference in fertilization success was observed at concentrations of 117  $\mu\text{g l}^{-1}$  and higher. The authors suggest *L. compactum* is significantly more resistant to copper than other previously studied coral species because the concentrations of copper required to significantly effect fertilization are much higher. They relate this to the fact that *L. compactum* has a two yearly gametogenic cycle as compared to the 4-9 month gametogenic cycle of all known hard corals.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Copper, Heavy metal, Fertilization

Scott, P. and M. Davies. 1997. Retroactive determination of industrial contaminants in tropical marine communities. *Marine Pollution Bulletin* **34**: 975-980.

Coupled plasma/mass spectrometry was used to detect metals in corals from two sites near an oil company, Irian Jaya and Java Sea, and one control site in the open ocean. Zn, Cu, Al, Cr, Cd, Sn, Pb, and Ni were found in corals from Irian Jaya, Indonesia. However, concentrations of these metals were significantly higher at the control site than Irian Jaya. Zn, Cu, Al, Cr, Pb, Ni, and V were detected in corals from Java Sea, Indonesia. Concentrations of these metals were significantly higher than at the control site. Most of the metals (Zn, Cu, Al, Cr, Sn, Pb, U, and V) that were detected are also used in marine anti-fouling paints. Based on these results the authors suggest caution in making any assumptions regarding the sources of metal contamination in corals because the metals found in coral skeletons may not be those that were predicted by the environmental conditions surrounding those corals.

Description of work: Field and Laboratory. Location: Indo-Pacific. Keywords: Coral, Heavy metal

Scott, P. J. B. 1990. Chronic pollution recorded in coral skeletons in Hong Kong. *Journal of Experimental Marine Biology and Ecology* **139**: 51-64.

The change in condition of the coral community from 1980 to 1986 was examined with respect to coral cover, species composition, growth rate, and heavy metal skeletal inclusion. This study was performed in response to a government initiated program to relocate large numbers of people from overpopulated areas of Hong Kong to some areas that were less populated. This increase in human and domesticated animal populations to these new areas occurred over a very short time period and presented a dramatic increase in pollution including sewage effluent and agricultural runoff to the coastal environment. The authors found that there was a decrease in coral cover as well a decrease in species diversity over this time. The corals also showed an increase in Mn, Zn, Ag, and Pb. The authors suggest that these changes reflect an enrichment of these metals in waters coming from the Hija River.

Description of work: Field. Location: Asia. Keywords: Coral, Heavy metal

Victor, S. and R. Richmond. 2005. Effect of copper on fertilization success in the reef coral *Acropora surculosa*. *Marine Pollution Bulletin* **50**: 1433-1456.

*Acropora surculosa* colonies were exposed to various concentrations of copper (Cu) to determine its effects on fertilization success. Cu significantly reduced fertilization at concentrations of 10 ug/l. At concentrations of 200 ug/l, fertilization occurred in less than 10% of colonies. The mechanism of toxicity is not clearly understood. The authors suggested that future research be directed towards the effects of Cu on sperm cells and egg cells alone to determine which is more affected. The authors also suggested that monitoring for Cu near coral reefs is necessary to prevent further reductions in coral fecundity.

Description of work: Field and Laboratory. Location: Asia-Pacific. Keywords: Heavy metal

### **Herbicides/Pesticides**

Broward County Environmental Quality Control Board. 1981. Annual update: Environmental assessment of the north and south regional wastewater outfalls in the Atlantic Ocean at Broward County, Florida. 21 pp.

This annual update discusses two wastewater treatment plants in Broward County: the North Regional Wastewater Treatment Plant, outfall at 2.377 km offshore at 35 m deep; and the South Regional Wastewater Treatment Plant, outfall at 3.05 km offshore at 30 m deep. Discharge capabilities from these plants are 66.0 MGD (million gallons per day) and 40.0 MGD respectively. However, actual discharges measured October 1981 were 34.39 MGD and 32.98 MGD respectively. Both discharge points are visible from the surface on calm days and are located east of the "third reef" community. A study was conducted to determine if the effluent from these outfalls has had effects on the physical conditions of the surrounding environment through visual diver observation, bivalve collection, and photographic documentation. Six sites were studied for three experimental areas and three "control" areas. Control areas were considered areas not under the direct influence of an outfall discharge. Bivalves were collected



and examined for the presence of zinc, cadmium, PCB's and pesticides. Examination the bivalve tissue samples for pesticides and PCB's contained less than the minimum detection limits in all cases. The minimum detection limit for cadmium was 0.25 mg/kg. Seven of the 24 samples were reported as less than the detection limit for cadmium. Statistical analysis showed site 3 (onshore, south side of North Regional Discharge outfall) to have a significantly greater mean zinc value than the other sites. Site 4 (offshore, ~3 miles south of North Regional Discharge outfall) had a significantly higher mean cadmium value than the other sites. Since site 3 is close to the Hillsboro inlet it is presumably under a greater influence from land runoff and tidal exchange and this could be the reason for the zinc content. Overall, one sample from each site resulted in no detection of pesticides of PCB's. Examination of four samples from each of the six sites for zinc and cadmium showed that bivalves from the shoal area south of the Hillsboro Inlet have significantly higher zinc content and animals from the third reef due west of Commercial Blvd. contained significantly higher amounts of cadmium. The results imply that urban runoff is the probable source of these measured differences.

Description of work: Field and Laboratory. Location: Broward county, Florida. Keywords: Outfall, North and South Regional Wastewater Treatment Plant, Bivalve, Pesticides, PCB, Cadmium, Zinc

Connelly, D., J. Readman, A. Knaps and J. Davies. 2001. Contamination of the coastal waters of Bermuda by organotins and the Triazine herbicide Irgarol 1051. *Marine Pollution Bulletin* **42**: 409-414.

Tributyl tin (TBT) was the most common compound found in antifouling paints until it was banned in 1990. TBT causes detrimental effects to the environment in extremely low concentrations (less than 0.5 ng l<sup>-1</sup>), making it the most toxic substance ever introduced into the environment according to Goldberg (1986) and Maguire (1987). Endosymbiotic algae within coral were found to be vulnerable to the effects of TBT-based antifouling paints. In this study changes in the concentration of TBT were based on samples taken from 10 locations along the Bermuda coastline from 1988 through 1995. Overall, concentrations of TBT in the water column were found to decrease at all sampling sites from 1988-1995, indicating that the 1990 ban on organotin-based antifouling paints has been effective. Concentrations are still higher than the recommended environmental quality standard of 2 ng l<sup>-1</sup> and the authors suggest that this could be due to: 1) illegal use of TBT-based paints, 2) leaching from large vessels (cruise ships or container vessels) that are permitted to use TBT-based paints, or 3) resuspension of sediment sources.

Description of work: Field. Location: Caribbean. Keywords: Coral, Herbicide, Pesticide, Antifouling

Dahl, B. and H. Blanck. 1996. Toxic effects of the antifouling agent Irgarol 1051 on periphyton communities in coastal water microcosms. *Marine Pollution Bulletin* **32**: 342-350.

Marine periphyton were exposed to Irgarol 1051 in concentrations ranging from 0.06 to 260 nM over a three week period. Periphyton photosynthetic ability was significantly reduced at 3.2 nM concentrations of Irgarol 1051 during short-term observations (hours). In the long-term study (weeks) significant changes in community structure and reduction in photosynthetic ability were

observed at concentrations of 1.0 nM.

Description of work: Field and Laboratory. Location: Europe. Keywords: Coral, Herbicide, Irgarol 1051

Downs, C., R. Owen, L. Buxton and A. Downs. Preliminary examination of cellular toxicological responses of the coral *Madracis miabilis* to acute Irgarol 1051 exposure: application of cellular diagnostics. EnVirtue Biotechnologies Manuscript 1-30.

Samples of *Madracis miabilis* were exposed to  $10\mu\text{gL}^{-1}$  concentrations of Irgarol 1051 for periods of 8 and 24 hours. Cellular diagnostics were then used to determine changes in protein metabolic condition, oxidative damage and response, metabolic homeostasis and xenobiotic response in both host and zooxanthellae. Results suggested that Irgarol 1051 impacts porphyrin synthesis and causes oxidative stress which may increase the corals risk of bleaching.

Description of work: Laboratory. Location: Caribbean. Keywords: Herbicide, Irgarol 1051, Coral

Fisher, L. E. 1980. Annual update: Environmental assessment of the Broward County North Regional Outfall. 15 pp.

This annual update was done to determine if the presence of the North Broward (Pompano) outfall and its discharge has had any effect on the physical conditions of the surrounding environment. The Pompano outfall terminus is located 2.377 km offshore just south of the Hillsboro Inlet at a depth of 35 m. The "third reef" is 150 m west of the outfall terminus in 30 m of water and rises to 15 m over a distance of 100 m. Analysis of grain size distribution was done to determine if bottom sediment consistency has remained the unchanged. Sediment analysis was performed to look for the presence of selected trace metals, pesticides, and PCB's attributed to the discharge. Results of the grain size distribution analysis showed no significant difference between the control site and the outfall site. The chemical analysis of bottom sediments showed no pesticides or PCB's above the detection limits. Comparison of chemical analyses of the present study with one performed in 1978-79 shows slight increases for cadmium, chromium, lead, zinc, and nickel with no change or decreases for copper, iron and all chlorinated hydrocarbons. Chromium showed a significant decrease at the terminus of the outfall, lead at the terminus is twice the amount of other sites, and nickel shows a high concentration at the easternmost and deepest site. Overall, no changes have occurred in the consistency of bottom sediments between control and outfall samples. Differences (positive or negative) observed for the trace metals, pesticides, and PCB's may or may not be real; the variability may occur naturally in the sediment. No visual changes in the outfall environment were observed.

Description of work: Field and Laboratory. Location: Pompano, Florida. Keywords: Pompano Outfall, Sediment, Pesticide, PCB, Trace metal, Cadmium, Chromium, Lead, Zinc, Nickel, Copper, Iron

Glynn, P. W., A. M. Szmant, E. F. Corcoran and S. V. Cofer-Shabica. 1989. Condition of coral reef cnidarians from the northern Florida reef tract: Pesticides, heavy metals, and histopathological examination. *Marine Pollution Bulletin* **20**: 568-576.

This study compared two coral reefs in Biscayne National Park. Each reef contained Scleractinian coral and octocoral assemblages. Abundance, field condition, concentrations of pesticides and heavy metals, and histopathological condition were determined for both communities. It was hypothesized that the coral reef closest to the input of urban pollution would be more degraded than the one further from the source. No significant differences were found between the two coral reef communities. Reef degradation, indicated by blemishes, abnormalities, bleached and dead tissue, and invading pathogens were found on both reefs. Organochlorine pesticides and heavy metals were also found at high but relatively equal concentrations in samples from both reefs.

Description of work: Field. Laboratory. Location: Florida. Keywords: Pesticide, Coral, Heavy metal, Herbicide

Goldberg, E. 1986. TBT: An environmental dilemma. *Environment ENTVAR* **28**: 17-20, 42-44.

Many studies have been performed regarding the toxicity of tributyl tin (TBT) on phytoplankton, zooplankton, macro- and microinvertebrates. The author suggests that most of these studies have underestimated the concentrations at which TBT is toxic since the concentrations are not generally measured in the water during these experiments. The author also suggests that short term laboratory studies can not predict the actual toxicity of TBT because it is a slow acting compound and that microbial and photochemical processes also need to be taken into account. TBT can cause a number of effects including neurotoxic effects and epithelial tissue distortion. The author states that marine organisms in the younger life stages are more susceptible to TBT toxicity than mature organisms. Based on these observations, the author suggests that TBT use be banned completely for all commercial and pleasure water craft.

Description of work: Review. Location: None. Keywords: Herbicide, Pesticide

Griffin, D. W., C. A. Kellogg, V. H. Garrison and E. A. Shinn. 2002. The global transport of dust. *American Scientist* **90**: 228-235.

This review addresses the effects of dust storms on the Earth. Dust lifted up into the atmosphere is due to storms, but this dust is carrying more than just dirt. Dust particles can carry pollutants such as herbicides, pesticides, bacteria, viruses, and fungi. Estimates show that 13 million metric tons of African dust sediment fall on the North Amazon Basin of South America every year. Dust storms in North Africa also affect air quality in Europe and the Middle East. Investigations into the microbes present in the dust indicate that 25 percent are species of bacteria or fungi plant pathogens and 10 percent are human pathogens. Evidence shows that human health and coral reef communities have been affected by the dust phenomenon.

Description of work: Review. Location: None. Keywords: Coral community, Dust, Herbicides, Pesticides, Bacteria, Viruses, Fungi, Pathogens, Human health

Guzman, H. and C. Jimenez. 1992. Contamination of coral reefs by heavy metals along the Caribbean coast of Central America. *Marine Pollution Bulletin* **24**: 554-561.

*Siderastrea siderea* were surveyed along 23 reef tracts to determine concentrations of 12 different heavy metals (Al, V, Cr, Mn, Fe, Ni, Cu, Zn, Cd, Pb, Sn, and Ba). Sn and Ba were not detected at any of the sites, however methods used would not have detected these metals in small quantities. No pattern was found with metal concentrations between study sites. Most metals were detected at all sites, even those sites deemed to be "pristine" although in lower concentrations. Al, Fe, and Mn were detected in the highest concentrations in both sediments and coral skeletons. Possible sources of metals in this area include; discharge by oil tankers, antifouling paints, oil spills, fertilizers, lime, and pesticides.

Description of work: Field. Location: Caribbean. Keywords: Coral, Heavy metal, Pesticide

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Harrington, L., K. Fabricius, G. Eaglesham and A. Negri. 2005. Synergistic effects of diuron and sedimentation on photosynthesis and survival of crustose coralline algae. *Marine Pollution Bulletin* **51**: 415-427.

The effects of sedimentation on three species of crustose coralline algae (CCA) were examined. The effects of diuron and sedimentation, separately and combined, was tested on one species of CCA. Results showed significant differences in sedimentation tolerance between the species. At environmentally relevant concentrations, diuron alone caused a decrease in photosynthesis of the CCA. At high diuron concentrations visible bleaching was observed. In these cases the effects were reversible when the samples were transferred to clean seawater. Bioassays using diuron and sediment caused a decrease in photosynthesis and irreversible damage to the CCA. Bleaching from chloroplast destruction and mortality was observed. The authors suggested that if the experimental conditions closely replicated field conditions then CCA could be severely

affected by exposure to terrestrial runoff.

Description of work: Laboratory. Location: Australia. Keywords: Sediment, Herbicide, Pesticide, Coral

Jones, R. J. and A. P. Kerswell. 2003. Phytotoxicity of photosystem II (PSII) herbicides to coral. *Marine Ecology Progress Series* **261**: 149-159.

The effects of eight photosystem II inhibiting herbicides on the zooxanthellae of the coral, *Seriatopora hystrix*, were examined. By measuring photosynthetic efficiency of the symbionts, the phytotoxicity of the herbicides were ranked from high to low: Irgarol 1051>ametryn>diuron>hexazinone>atrazine>simazine>tebuthiuron>ioxynil. Experiments to test the effect on toxicity of herbicides with increasing temperature were also conducted. Initially, diffusion of diuron into symbiont cells was slower at 20C than at 30C. However, over time diuron diffusion at 20C increased and the herbicide became more toxic than at 30C. In general the author suggests that toxicity of diuron does not increase with increasing temperatures.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Herbicide, Pesticide

Jones, R. J., J. Muller, D. Haynes and U. Schreiber. 2003. Effects of herbicides diuron and atrazine on corals of the Great Barrier Reef, Australia. *Marine Ecology Progress Series* **251**: 153-167.

The effects of the pesticides diuron and atrazine on symbiotic dinoflagellates of corals were tested. Zooxanthellae samples from four species of coral were collected from unpolluted reefs within the Great Barrier Reef Marine Protected Area. Bioassays were conducted on the coral symbionts. The change in the photosynthetic efficiency during the treatments showed that diuron was more toxic than atrazine. The effects of diuron were rapid but reversible when samples were returned to clean flowing seawater. The results also showed that light intensity did affect the toxicity of diuron but salinity changes did not.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Diuron, Atrazine, Herbicide, Pesticide

Konstantinou, I. and T. Albanis. 2004. Worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment: a review. *Environment International* **30**: 235-248.

A review of present data on worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment. Concentrations are generally higher in areas of increased recreational boating traffic like marinas and harbors. The authors suggest continuous monitoring of water, sediments, and biota to track changes in biocide concentrations and their degradation products. They also suggest putting restrictions on the amount of usage of these antifouling products

Description of work: Review. Location: None. Keywords: Coral, Herbicide

Macauley, J. M., J. K. Summers, V. D. Engle and L. C. Harwell. 2002. The ecological condition of South Florida estuaries. *Environmental Monitoring and Assessment* **75**: 253-269.

The ecological condition of South Florida estuaries was assessed based on regional monitoring during the summer of 1995. Samples were collected and measurements made on water and sediment quality, benthos, and fish tissue contaminants. Findings showed elevated concentrations of metals and pesticides in sediments and fish tissue with some levels exceeding guidance values. Dissolved oxygen levels of the bottom over 23-37% of the area were below state criteria. The study area spanned Anclote Key to the mouth of the Indian River. Based on a calculated index of ecological condition, 9% of the area exhibited degraded biology and impaired use.

Description of work: Field. Location: East coast, South Florida. Keywords: Inlet, Ecological condition, Environmental assessment, Water quality, Sediment, Benthos, Fish tissue, Metals, Pesticides, Oxygen

Maguire, R. 1987. Environmental aspects of tributyltin. *Applied Organometallic Chemistry* **1**: 475-498.

Tributyltin (TBT) may be the most toxic substance ever introduced into the marine environment. TBT can be lethal to some aquatic organisms in concentrations less than 1 ug/dm<sup>3</sup>, and chronic toxicity can occur at concentrations less than 0.1 ug/dm<sup>3</sup>, acute toxicity has been observed at concentrations of 0.002 ug/dm<sup>3</sup>. TBT exhibits a moderate potential for bioaccumulation within aquatic organisms. Concentrations of TBT in the waters and sediments of harbors, marinas, and shipping channels are much higher than open ocean areas, indicating that antifouling paints are the source. The author suggests that future approaches to toxicity testing of TBT use flow-through conditions with continuous measurements of TBT concentrations throughout the experiment. The author also suggests that the persistence of TBT be determined for various ecosystems in order to make better predictions for other locations.

Description of work: Review. Location: None. Keywords: Herbicide, Pesticide, TBT

Morgan, M. and T. Snell. 2002. Characterizing stress gene expression in reef-building corals exposed to the mosquitoside dibrom. *Marine Pollution Bulletin* **44**: 1206-1218.

This study examined gene expression in response to dibrom exposure. Two gene probes were isolated and named D25 and D50. The D25 probe had a toxicant and concentration specific expression for organophosphates and nor expression in control colonies. The D50 probe had a broader expression responding to dibrom, naphthalene, and temperature stress. Therefore the D50 probe cannot be specifically linked to dibrom exposure. The D25 probe cannot be specifically linked to dibrom exposure either because it has not been tested against other chemicals and may yet illicit a response to some other stressor. The authors suggest that corals respond to stressors by expressing different genes and that the D25 probe may provide a link between organophosphate exposure and changes in coral stress gene expression.

Description of work: Laboratory. Location: Florida. Keywords: Dibrom, Coral, Pesticide, Florida

## Keys

Moss, A., J. Brodie and M. Furnas. 2005. Water quality guidelines for the Great Barrier Reef World Heritage Area: a basis for development and preliminary values. *Marine Pollution Bulletin*. **51**: 76-88.

This paper discussed how to establish local and regional water quality guidelines from existing federal guidelines. Nutrients, sediments and agricultural chemical impacts from adjacent catchments are addressed with respect to two types of water quality guidelines, pressure and biological response indicators. Region specific guidelines based on the methodologies of ANZECC guidelines were proposed. Water temperature,  $^{15}\text{N}$ , and diuron were specifically mentioned. It was concluded that currently there are not adequate indicators to determine if biological impacts on reefs are due to water quality alone in the GBRWHA. The authors made the following recommendations: develop indicators using a mix of stressors and compile adequate data sets to establish guidelines.

Description of work: Review. Location: Australia. Keywords: Nutrient, Sediment, Herbicide, Pesticide, Coral

Negri, A. and A. Heyward. 2001. Inhibition of coral fertilisation and larval metamorphosis by tributyltin and copper. *Marine Environmental Research* **51**: 17-27.

Copper (Cu) and tributyltin (TBT) are found in antifouling paints. This study tested the effects of these two substances on fertilization success and larval metamorphosis in *Acropora millepora*. Cu inhibited fertilization in 50% of *A. millepora* gametes at concentrations of 17.4 ug/l ( $\pm 1.1$ ). TBT inhibited fertilization in 50% of *A. millepora* gametes at concentrations of 200 ug/l ( $\pm 31$ ). Cu inhibited metamorphosis in 50% of *A. millepora* larvae at concentrations of 110 ug/l ( $\pm 20$ ). TBT inhibited metamorphosis in 50% of *A. millepora* larvae at concentrations of 2.0 ug/l ( $\pm 0.3$ ). Antifouling paints which contained a mixture of TBT and Cu inhibited fertilization and metamorphosis of *A. millepora* by 100%. Both TBT and Cu had toxic effects at nominal concentrations close to those set by EPA guidelines. The authors concluded that coral fertilization and metamorphosis is negatively affected by both TBT and Cu. The authors also suggest that more research be done to assess the impacts of these and other compounds on reef building corals in order to better monitor and regulate their usage in antifouling paints.

Description of work: Laboratory. Location: Australia. Keywords: Herbicide, Pesticide, Heavy metal, Coral

Negri, A., L. Smith, N. Webster and A. Heyward. 2002. Understanding ship-grounding impacts on a coral reef: potential effects of anti-foulant paint contamination on coral recruitment. *Marine Pollution Bulletin* **44**: 111-117.

Studies were performed following a collision of a 184 m cargo ship with a portion of the Great Barrier Reef (GBR) to determine the toxicity effects to the reef from the ships antifouling paint which contained tributyl tin (TBT), copper and zinc. In a laboratory experiment *Acropora*

*microphthalma* larvae were exposed to sediments collected from the grounding site. Sediments containing 8.0 mg/kg of TBT, 72 mg/kg copper, and 92 mg/kg zinc significantly inhibited larval settlement and metamorphosis. Although the larvae survived this exposure, it was observed that the larvae contracted into spherical shapes and stopped swimming altogether. One hundred percent larval mortality was observed at higher concentrations. The authors suggest that these studies are relevant because the grounded cargo ship was removed from the reef just 3 days before a mass spawning event. The authors also suggested that long term study is needed to determine the chronic effects of this ship grounding event.

Description of work: Field and Laboratory. Location: Australia. Keywords: Herbicide, Pesticide, Coral

Negri, A., C. Vollhardt, C. Humphrey, A. Heyward, R. Jones, G. Eaglesham and K. Fabricius. 2005. Effects of the herbicide diuron on the early life history stages of coral. *Marine Pollution Bulletin* **51**: 370-383.

Laboratory experiments were done to determine the effects of diuron on early life stages of broadcast spawning and brooding corals in the Great Barrier Reef (GBR). Diuron has a relatively high solubility and long half-life, and it is widely used along the GBR in sugar cane fields. In relatively low concentrations ( $1\mu\text{g l}^{-1}$ ) diuron interferes with photosynthesis of coral biosymbionts by inhibiting photosystem II. This study found that diuron did not effect fertilization because this process generally occurs at night and is not dependent on photosynthesis. Diuron had little effect on larval metamorphosis, except in one species, *Acropora millepora*, at very high concentrations. Diuron had no effect on the symbiont-free *A. millepora* recruits after 96 hours of exposure at concentrations of 10-1000  $\mu\text{g l}^{-1}$ , however tissue retraction and irreversible bleaching was observed in symbiont-containing *Pocillopora damicornis* recruits. The authors also indicated that in situ corals would be exposed to higher concentrations of diuron during flood events which could correspond to seasons of mass spawning. These events would expose corals to a number of herbicides and pesticides, as well as increased nutrients, salinity and temperatures that could compound the effects of diuron alone.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Herbicide, Pesticide, Diuron

Olafson, R. W. 1978. Effect of agricultural activity on levels of organochlorine pesticides in hard corals, fish and molluscs from the Great Barrier Reef. *Marine Environmental Research* **1**: 87-107.

This study established a baseline for organochlorine levels in the nearshore marginal reefs of the Great Barrier Reef. A number of pesticides were used in an adjacent agricultural area and it was hypothesized that terrestrial runoff would transport these chemicals to nearshore waters. Two species of fish, two scleractinian corals and one bivalve mollusc were examined for organochlorine concentrations. Analysis of the animals revealed that Lindane was the only organochlorine pesticide present in the marginal reef environments. The authors suggested that the major transport of Lindane to the Great Barrier Reef occurred via river runoff.

Description of work: Field. Location: Australia. Keywords: Lindane, Organochlorine, Pesticide,



Coral, Herbicide, Pesticide

Ongley, E. D. 1996. Control of water pollution from agriculture. Food and Agriculture Organization of the United Nations **55**: 68 pp.

This publication addresses the agricultural operations that can contribute to water quality deterioration such as: sediments, pesticides, animal manurers, fertilizers and other sources of inorganic and organic matter. The Food and Agriculture Organization of the United Nations has recognized the key role of water in agricultural development and implemented a Regular Programme on Water Resources Development and Management. Recommendations are given for control of sediment, fertilizer, and pesticide impacts on water quality.

Description of work: Review. Location: Canada. Keywords: Agricultural operations, Sediment, Pesticide, Fertilizer, Water Quality

Owen, R., A. Knap, M. Toasperm and K. Carbery. 2002. Inhibition of coral photosynthesis by the antifouling herbicide Irgarol 1051. *Marine Pollution Bulletin* **44**: 623-632.

Irgarol 1051 concentrations were measured in the waters of the Florida Keys, St. Croix, and Bermuda. Concentrations were found to be in the range of 3-294 ng l<sup>-1</sup>. <sup>14</sup>C incorporation into zooxanthellae was measured. There was no <sup>14</sup>C incorporation after a 6 hr exposure to Irgarol 1051 at concentrations of 63 ng l<sup>-1</sup>. Photosynthesis was reduced in all corals at Irgarol 1051 concentrations of 100 ng l<sup>-1</sup> compared to controls, and no photosynthesis was observed at concentrations of 1000 ng l<sup>-1</sup> and greater. This study showed that Irgarol 1051 is present in tropical marine waters and that it inhibits coral photosynthesis and zooxanthellae <sup>14</sup>C incorporation.

Description of work: Field and Laboratory. Location: Caribbean and Florida. Keywords: Coral, Herbicide, Irgarol, Pesticide

Peters, E. C., N. J. Gassman, J. C. Fireman, R. H. Richmond and E. A. Power. 1997. Eco toxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* **16**: 12-40.

Information gaps related to the effects of chemical contaminants on tropical marine ecosystems were evaluated. Heavy metals, petroleum, and synthetic organics were discussed in the context of ecosystem management and ecological risk assessment. Some of the most important sources of pollutants are terrestrial runoff, sewage outfalls, desalination plants, landfills, oil refineries and tanker spills. Coral colonies can be affected by all of these. Exposure to heavy metals causes production of mucus and expulsion of symbiotes as a means of excretion, reduced growth rate and species diversity also occur in reefs exposed to metals. Research suggests that small scale chronic oil spills may be more toxic than single large scale spills. Dispersants in combination with oil also increased tissue death and bleaching events in corals. Studies show increasing levels of pesticides, particularly lindane, DDT, and chlordane in nearly 100% of corals in the Great Barrier Reef and reefs off the Florida Keys. In general, data on pollutants and biological responses is much more complete for temperate marine and freshwater systems. It has

not yet been established if the fate and transport of pollutants in tropical marine systems is similar to that of temperate systems. Most monitoring programs in tropical systems quantified ecological responses but provided limited data on the stressors. Data on toxic pollutant levels that caused adverse effects in the field are limited. The author suggests that studies need to be done where contaminant levels in the water, sediment, and organisms are all measured at the same time in the same locations, and that researchers need to use the latest technology and appropriate identification protocols to produce more accurate results.

Description of work: Review. Location: None. Keywords: Coral, Heavy metal, Pharmaceutical, Organic, Pesticide, Herbicide

Raberg, S., M. Nystrom, M. Eros and P. Plantman. 2003. Impact of the herbicides 2, 4-D and diuron on metabolism of the coral *Porites cylindrica*. *Marine Environmental Research* **56**: 503-514.

The effects of two herbicides on *Porites cylindrica* were analyzed by measuring changes in production, respiration and photosynthesis. Gross primary production rate, production to respiration ratio and photosynthesis decreased when exposed to high concentrations of the ionic herbicide 2,4-D. These three parameters were significantly reduced when exposed to relatively low concentrations of diuron. In general, diuron was found to be more toxic at lower concentrations (3 orders of magnitude) than the herbicide 2,4-D.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Coral, Diuron, Herbicide, Pesticide

### **Inlets**

DHI Water and Environment, Inc. 2003. Modeling of wave, hydrodynamic and sediment transport processes in connection with the bypassing of sand at Port Everglades entrance. Status Report 89 pp.

This report discusses the work being done to carry out a numerical model in support of the ongoing feasibility study for the bypassing of sand across Port Everglades Inlet, Florida. Presented is the setup and calibration of the regional hydrodynamic model as well as summary of the setup of the local wave, hydrodynamic and sediment transport models for existing site conditions.

Description of work: Report. Location: Port Everglades, Florida. Keywords: Inlet, Hydrodynamic modeling, Wave modeling, Sediment transport modeling, Port Everglades, Sediment

Finkl, C. W. and R. H. Charlier. 2003. Sustainability of subtropical coastal zones in Southeastern Florida: Challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. *Journal of Coastal Research* **19**: 934-943.

The authors address the intense urbanization along southeastern Florida from West Palm Beach

to Miami and the effects to the Florida Reef Tract, the Biscayne Aquifer, submarine groundwater discharge, nutrient loading, coastal water quality, and tourism-related activities. Submarine groundwater discharge (SGD) causes an increase in nutrients to the Florida Reef Tract through the Biscayne Aquifer. This aquifer has one of the highest carbonate aquifer transmissivities in the world. Groundwater discharges in Palm Beach County are estimated at  $1,659 \times 10^6$  m<sup>3</sup>/yr. Nutrient fluxes from SGD to the coastal ocean are 5727 metric tons of phosphorous and 414 metric tons of nitrogen per year, while surface water contributions are 197 metric tons for phosphorous and 2471 metric tons for nitrogen per year. It is estimated that SGD is approximately 133% of surface water discharge. The authors suggest that the major source of these nutrients is sugar cane farming and that current approaches to remedy the situation will fail because they are focused on treating the symptoms not the cause of the problem. Topics addressed include: sustainability of beach systems and of agro-urban coastal environments; and the status quo and sustainability prognosis.

Description of work: Review. Location: Southeastern Florida. Keywords: Inlet, Environmental integrity, Submarine Groundwater discharge, Nutrient loading, Water quality, Remediation, Coastal Management, N, P

Macauley, J. M., J. K. Summers, V. D. Engle and L. C. Harwell. 2002. The ecological condition of South Florida estuaries. *Environmental Monitoring and Assessment* **75**: 253-269.

The ecological condition of South Florida estuaries was assessed based on regional monitoring during the summer of 1995. Samples were collected and measurements made on water and sediment quality, benthos, and fish tissue contaminants. Findings showed elevated concentrations of metals and pesticides in sediments and fish tissue with some levels exceeding guidance values. Dissolved oxygen levels of the bottom over 23-37% of the area were below state criteria. The study area spanned Anclote Key to the mouth of the Indian River. Based on a calculated index of ecological condition, 9% of the area exhibited degraded biology and impaired use.

Description of work: Field. Location: East coast, South Florida. Keywords: Inlet, Ecological condition, Environmental assessment, Water quality, Sediment, Benthos, Fish tissue, Metals, Pesticides, Oxygen

Militello, A. and G. A. Zarillo. 2000. Tidal motion in a complex inlet and bay system, Ponce de Leon Inlet, Florida. *Journal of Coastal Research* **16**: 840-852.

Tidal motion at Ponce de Leon Inlet, and its adjacent bay channels was examined by field measurements and application of a two-dimensional, depth-integrated hydrodynamic numerical model. Water level and current were measured at six locations for a 10-week period spanning the ebb shoal, inlet, and bay channels. Findings showed the inlet was flood dominated and this dominance may be enhanced by a net influx of water during the measurement period. Scour, erosion, and sedimentation are problems at Ponce Inlet, and calculations suggest tide-related circulation patterns contribute to hot spots in the area.

Description of work: Field and Laboratory. Location: Ponce de Leon, Florida. Keywords: Inlet, Hydraulics, Tidal attenuation, Flood, Circulation modeling,

Broward County Department of Planning and Environmental Protection. 2001. Broward County, Florida Historical Water Quality Atlas: 1972-1997. Technical Report **TR: 01-03**: 415 pp.

Since 1972 the Broward County Department of Planning and Environmental Protection (BCDPEP) has monitored the water quality of Broward County's waterways. The goal of the BCDPEP since 1988 has been to understand ambient water quality conditions throughout the urban portions of the county as part of the habitat realm of biological populations they may sustain. This atlas provides a comprehensive update on the county's ambient water quality and depicts historical characteristics from 1972-1997.

Description of work: Technical Report. Location: Broward County. Keywords: Water quality, Broward county, Surface waters, Inlets, Outfalls

Sigua, G. C., J. S. Steward and W. A. Tweedale. 2000. Water-quality monitoring and biological integrity assessment in the Indian River Lagoon, Florida: Status, Trends, and Loadings (1988-1994). *Environmental Management* **25**: 199-209.

The Indian River Lagoon (IRL) system extends from Ponce de Leon Inlet to Jupiter Inlet on Florida's east coast. The IRL is subdivided into North and South and is comprised of three interconnected estuarine lagoons. Declines in coverage and species diversity of seagrass communities are believed to be due in part to degradation of water quality. Inflows of phosphorus and nitrogen laden storm water from urban areas and agricultural land have been correlated with higher chlorophyll *a* production. Total Kjeldahl nitrogen was higher in the north than the south section of the IRL while total phosphorus was lowest in the north and highest in the south. Monitoring of the IRL is important to develop water-quality management priorities and plans to direct pollution control toward point and nonpoint sources, and to implement water-quality programs, such as establishing permit limits. This paper describes site-specific differences of water quality and nutrient loading distributions in the IRL system.

Description of work: Field. Location: Indian River Lagoon, Florida. Keywords: Inlet, Phosphorus, Nitrogen, Management, Monitoring, Water quality, Estuary, Seagrass, Nutrient loading

Wang, J. D., J. Luo and J. S. Ault. 2003. Flows, salinity, and some implications for larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science* **72**: 695-723.

Data on tides, wind and freshwater inflows were combined with physical and biological performance tests to develop a numerical model. The model was used to predict currents, residence times, salinity patterns and shrimp larval transport in S. Florida. Model predictions regarding tidal currents were found to be within 0.01 m/s of the observed values. Direct currents are controlled by tide while sub tidal currents are controlled by wind. Sub tidal currents were found to have a large effect on residence times. Model predictions of salinity and currents correlated well with data observations. The authors suggested that the model could be used to estimate spatial shrimp population dynamics, making it useful for ecological risk assessment with regards to water management, Everglades restoration, and climate change.

Description of work: Field and Laboratory. Location: Biscayne Bay, Florida. Keywords: Inlet, Hydrodynamics, Salinity, Currents, Larval transport, Water management, SGD, Everglades

## Restoration

### Nutrients

Alongi, D. M. and A. D. McKinnon. 2005. The cycling and fate of terrestrially-derived sediments and nutrients in the coastal zone of the Great Barrier Reef shelf. *Marine Pollution Bulletin*. **51**: 239-252.

This study examined the fate of terrestrially derived nutrients once they entered the Great Barrier Reef World Heritage Area (GBRWHA) coastal zone. The study concluded that most of that nutrients derived from terrigenous sources were metabolized by microbes in the GBRWHA coastal zone and not exported to the middle or outer shelf areas of the Great Barrier Reef. Nutrient budget calculations indicated that microbial mineralization rate exceeded the total nutrient load from river input and that insitu processes such as: N-fixation by benthic and pelagic microbes is an important source of nutrients to this system. The geography and oceanography of the coastal zone also restricted off shore transport of sediment and nutrients (i.e. Mangrove forests).

Description of work: Review. Location: Australia. Keywords: Nutrient, Coral, Sediment, Metabolism

Barile, P. J. 2004. Evidence of anthropogenic nitrogen enrichment of the littoral waters of east central Florida. *Journal of Coastal Research* **20**: 1237-1245.

This study analyzed water samples from the littoral coastline of Brevard and Indian River County, Florida. The quartz sand barrier island geology of the test area facilitated the formation of submarine groundwater discharges of barrier island aquifers, driven by tidal pumping.  $^{15}\text{N}$  data was examined to differentiate the source of dissolved inorganic nitrogen to the system with respect to upwelling, sewage, nitrogen fixation, and fertilizer. Analysis of  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$  and soluble reactive phosphorous concentrations showed that on average over half the dissolved inorganic nitrogen present was  $\text{NH}_4^+$  and the highest DIN concentrations were associated with rainfall events. The DIN values were in excess of threshold values required to support blooms of the red tide species *Karenia brevis* and various macroalgal species. The author suggested a link between anthropogenic nutrient availability and the presence of eutrophication-indicator macroalgal species. The  $\delta^{15}\text{N}$  values reported indicated that SGD is equally or more responsible for the delivery of sewage derived N to the system than any other source. However, analysis of fore reef macroalgae tissue also showed elevated values of  $^{15}\text{N}$  concentrations associated with upwelling events.

Description of work: Field. Location: Florida. Keywords: Sewage, Nutrient, Coral, SGD

Bell, P. 1992. Eutrophication and coral reefs-some examples in the Great Barrier Reef lagoon.

Water Resources **26**: 553-568.

Upon reviewing several studies regarding eutrophication of coral reefs in the Great Barrier Reef (GBR) lagoon, it was determined that chlorophyll a is the best water quality indicator for eutrophication. The authors suggest a threshold value of 0.5 mg/m<sup>3</sup> for chlorophyll a. The concentrations of nutrients, nitrogen (N) and phosphorus (P), indicative of eutrophication were more difficult to identify. The authors suggest using values of 1uM for N and 0.1-0.2 uM for P, which are comparable to those used in freshwater systems. Some near-shore regions of the GBR lagoon are already experiencing eutrophic conditions. The authors suggested that the cause of this is river run-off. Sewage discharge may also contribute to eutrophication events because this can deliver excess nutrients, organic matter and suspended solids to the reefs. The authors suggest that sewage discharge and run-off be carefully controlled in order to prevent further eutrophication of coral in the GBR lagoon.

Description of work: Review. Location: Australia. Keywords: Coral, Nutrient

Bell, P. and I. Elmetri. 1995. Ecological indicators of large-scale eutrophication in the Great Barrier Reef lagoon. *Ambio* **24**: 208-215.

It was determined that chlorophyll a concentrations were the best indication of the initial stages of eutrophication because it is an indication of increased phytoplankton fertility. The authors suggested that nutrient concentrations would not be a good indicator at the onset of eutrophication because they are taken up rapidly by the increasing phytoplankton and their concentrations in the water column may actually be quite low at this stage. Results from a study in 1992-1993 were compared with those of an earlier study performed by Marshall in 1928-1929. Both studies were performed at a location 3 miles east of Low Isles in the GBR lagoon. The data indicated that a significant increase in microphytoplankton. There was also a shift from a community dominated by centric and pennate diatoms in the 1928-1929 study, to a community dominated by small flagellates (<20um), causing a decreasing diatom/flagellate ratio since 1929. The authors list this as an indication of anthropogenic eutrophication and pollution. Results have also indicated that sediment and nutrient flux to the GBR lagoon has increased by a factor of 3-5. The authors state that these results demonstrate that there is no longer any part of the GBR lagoon that can be considered pristine. The eutrophication of the GBR lagoon has led to decreased ability of coral recovery and increased populations of *Acanthaster planci*, which can be devastating to the coral reefs.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Nutrient

Bellwood, D. R., T. P. Hughes, C. Folke and M. Nystrom. 2004. Confronting the coral reef crisis. *Nature* **429**: 827-833.

This article reviewed temporal and geographic variations in the resilience of Caribbean coral reefs to human impacts like nutrient and sediment from runoff. The subtle signs of reef degradation have often gone unrecognized until a phase shift was well underway. The common views of coral reef management were reassessed by examining the role of critical functional groups, specifically the herbivores (bioeroders, scrapers and grazers). Functional groups were defined "as a collection of species that perform a similar function, irrespective of their taxonomic

affinities". The species richness and taxonomic composition was used to determine the resilience of a functional group which dictates the range of tolerance to environmental changes. The number of functional groups present on a reef dictated its capacity to resist phase shifts. The following four recommendations were given for managing coral reef ecosystems: 1) the rate and size of No Take Zones should be increased dramatically; 2) the focus on NTZ's should not preclude resources being allocated to highly impacted and degraded reefs; 3) coral reef management policy should be more proactive and inclusive, by empowering users of the reefs as stewards; and 4) markets for reef resources need to be reformed to prevent exploitation of functional group species.

Description of work: Review. Location: Caribbean. Keywords: Coral, Resilience, Nutrient, Sediment, Phase Shift

Brodie, J. 1994. Management of sewage discharges in the Great Barrier Reef Marine Park. The Sixth Pacific Congress on Marine science and technology. 9.

Inputs of nutrient to coastal waters from primary, secondary and tertiary treated sewage were calculated from biochemical oxygen demand values, total N, total P, and surfactant concentrations. It was estimated that overall sewage outfall nutrient contributions were one tenth that of diffuse runoff from agricultural activity. Nutrients from sewage outfalls of large cities constituted a much higher percentage of total nutrient input than that of outfalls from lower populated areas.

Description of work: Review. Location: Queensland, Australia. Keywords: Sewage, Nutrients, N, P, Coral

Bruno, J. F., L. E. Petes, C. D. Harvell and A. Hettinger. 2003. Nutrient enrichment can increase the severity of coral diseases. *Ecology Letters* **6**: 1056-1061.

Results of the first *in-situ* examination of the effects of nutrient enrichment on coral diseases were reported. Nutrient enrichment was achieved using mesh bags with Osmocoat<sup>TM</sup> fertilizer anchored near the specimens. 10 individual *Montastraea sp* and 10 *Gorgonia ventalina* were categorized into four groups: control, infected control, enriched, and infected enriched. The results of the experiment suggested that moderate increases in nutrient concentrations can substantially increase the susceptibility of corals to diseases.

Description of work: Field. Location: Caribbean. Keywords: Nutrient, Coral, Disease

Burnett, B. and J. Chanton. 2000. The role of groundwater in the nutrient budget of Florida Bay. 1-40.

Radon and methane concentrations were determined from samples collected from wells, solution holes, canals, and Florida Bay in an effort to determine patterns of groundwater to surface water interactions in the Bay. Seepage meters were also used to determine direct groundwater flux estimates. It was found that groundwater in the eastern area of the Bay supplied  $110 \pm 60$

mmol/m<sup>2</sup>/y of nitrogen and 0.21 ± 0.11 mmol/m<sup>2</sup>/y of phosphorus to the Bay. Although these measurements are not uniformly found throughout the Bay, the authors suggested that submarine groundwater discharge is a significant source of nutrients to the Florida Bay.

Description of work: Field. Location: Florida. Keywords: SGD, nutrients

Cheevaporn, V. and P. Menasveta. 2003. Water pollution and habitat degradation in the Gulf of Thailand. *Marine Pollution Bulletin* **47**: 43-51.

Several pollution sources were examined with respect to their effects on fisheries, aqua culture, coral and mangrove resources, and oil and mineral resources in the Gulf of Thailand. The authors classified the pollution sources into four categories; untreated municipal and industrial wastewater, excess nutrients, trace metals contamination, and petroleum hydrocarbon contamination. Rapid population growth, followed by industrialization has depleted resources and led to a worsening in environmental quality. Untreated wastewater is listed as the principle problem affecting the area, followed by eutrophication. The authors found little evidence of petroleum hydrocarbon contamination from oil spills, but fears still exist that there may be a large scale spill in the future. Also, trace metal contamination seemed to be minimal. Although Thailand has implemented a program for marine pollution control including baseline monitoring studies, water quality standards, identification of pollution sources, pathways, and quantities, as well as some pollution control and rehabilitation efforts; many of these areas are still under-emphasized.

Description of work: Review. Location: Asia. Keywords: HAB, Nutrients, Coral, Thailand, Sewage, Organic

Cooper, S., J. Huvane, P. Vaithiyathan and C. Richardson. 1999. Calibration of diatoms along a nutrient gradient in Florida Everglades Water Conservation Area-2A, USA. *Journal of Paleolimnology* **22**: 413-437.

Surface soil diatom assemblages were studied along various nutrient gradients in Everglades Water Conservation Area-2A (WCA-2A). The biggest shifts in species composition were observed along the phosphorus (P) gradient. Several species differences were also observed along carbon (C), nitrogen (N), calcium (Ca), and biogenic silica (BSi) gradients, although they were not as significant as those along the P gradient. The authors suggested that occurrence of *Nitzschia amphibia* and *Nitzschia palea* could be used as an indicators of high P values, while *Achnanthes minutissima* and *Mastogloia smithii* could be used as an indicators of low P. It was further suggested that all of these species may be useful as monitoring tools for eutrophication in projects like the Florida Everglades Restoration Plan.

Description of work: Field and Laboratory. Location: Everglades, FL. Keywords: Nutrient, Everglades Restoration, Diatom

Costa Jr., O. S., Z. M. A. N. Leao, M. Nimmo and M. J. Attrill. 2000. Nitrification impacts on coral reefs from northern Bahia, Brazil. *Hydrobiologia* **440**: 307-315.



The contamination of groundwater and its pathway to coastal waters and fringing coral reefs of the east central coast of Brazil was examined. The study area included two transects from coastal lakes, across two sand barriers to the coral reefs. One transect was located in an urbanized area characterized with septic systems for waste disposal. The other transect crossed a geologically similar but uninhabited area. Pollution levels at the two sites were determined by analysis of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NO}_4^+$ ,  $\text{PO}_4$  and silicate. pH, salinity, temperature and fecal coliform concentrations were used as ground water tracers. Samples were taken in the dry and rainy seasons of 1997. Ecological assessment of the reef system was also conducted and quantified using data from 130 sites. All parameters were higher in the reef waters adjacent to the urbanized area. pH and fecal coliform values indicated human waste contamination of the ground water at the urbanized site. Silicate and salinity values suggested that eutrophication of coastal waters was occurring at the urbanized location. The reefs at the urbanized locations were found to be much more degraded than those adjacent to the uninhabited sites.

Description of work: Field. Location: South America. Keywords: Coral, Eutrophication, Sewage, SGD, Nutrient, Salinity, Temperature, pH, Fecal Coliform

Costanzo, S. D., M. J. O'Donohue and W. C. Dennison. 2000. *Gracilaria edulis* (Rhodophyta) as a biological indicator of pulsed nutrients in oligotrophic waters. *Journal of Phycology* **36**: 680-685.

Nutrient concentration data from a bay containing a sewage outfall was combined with in-situ enrichment data, from the ENCORE experiments, to evaluate the physiological response of the macroalgae *Gracilaria edulis* to nutrient pulse events. The nutrient concentrations ranged from 10 times ambient to 1000 times ambient levels. An increase in macroalgae amino acid (citrulline) concentration was observed at 10 times the ambient level. Increases in tissue % nitrogen and amino acids were measured at 100 times the ambient nutrient level. At 1000 times the ambient level increases in chlorophyll *a*, tissue % nitrogen and amino acid concentrations were found. The results suggested that *G. edulis* may be a useful bioindicator of nutrient pulse events.

Description of work: Field. Location: Australia. Keywords: Bioindicator, Macroalgae, Nitrogen, Sewage, Nutrient, Coral

Delgado, O. and B. E. Lapointe. 1994. Nutrient-limited productivity of calcareous versus fleshy macroalgae in a eutrophic, carbonate-rich tropical marine environment. *Coral Reefs* **13**: 151-159.

Laboratory enrichment experiments were carried out to identify the seasonal patterns of nutrient limited productivity in fleshy versus calcareous algae in a eutrophic, carbonate-rich area of the Florida Keys. A number of species of fleshy and calcareous algae were exposed to varying levels of pulsed nutrients in order to measure changes in productivity and calcification. The algae were exposed to varying levels of N, P and N+P over a period of 7-10 days in February 1990 and again in July of 1991. Fleshy algae productivity was found to be 3 times that of calcareous algae in all treatments. Calcareous algae productivity was limited primarily by N, where as fleshy algae species were limited by N and or P. Two fleshy algae species,

*Hydroclathrus clathratus* and *Ulva sp* were identified as indicators of elevated soluble reactive phosphorous concentrations. The low dissolved inorganic nitrogen:soluble reactive phosphorous ratio at the eutrophic study site was compared to oligotrophic sites in the Florida Keys. This suggested that nitrification caused a change from P to N limitation in carbonate-rich ecosystems. The nitrification of Florida Keys near shore waters enhanced the productivity of fleshy algae more than that of calcareous algae. The primary reason for reduction in carbonate accretion by calcareous algae was not eutrophication but the overgrowth of the faster growing fleshy algae. Description of work: Laboratory. Location: Florida. Keywords: N, P, Eutrophication, Macroalgae, DIN, SRP, Coral, Nutrient

Edinger, E. N., J. Jompa, G. V. Limmon, W. Widjatmoko and M. J. Risk. 1998. Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time. *Marine Pollution Bulletin* **36**: 617-630.

Transect surveys were taken on 15 reefs in three regions of Indonesia to estimate the relative decrease of coral species diversity associated with reef degradation. The type of degradation investigated was land-based pollution (sewage, sedimentation, and/or industrial pollution). Reefs subject to these stresses showed 30-50% reduced diversity at 3 m depth and 40-60% reduced diversity at 10 m depth relative to unpolluted reefs in each region. Physically damaged reefs (bombed or anchors) were ~ 50% less diverse at 3 m than undamaged reefs at the same depth. At 10 m depth the relative decrease in diversity due to physically damaged reefs was 10%.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Reef degradation, Biodiversity, Land-based pollution, Nutrient, Heavy Metal

Fabricius, K. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

This review focused on the direct effects of terrestrial runoff on coral reef communities at regional scales. The author identified inorganic nutrients and particulate matter as the most important contaminants of coral reefs on national and regional levels. Available data on the response of coral reef organisms to the following stressors was evaluated: increased dissolved inorganic nutrients; increased concentrations of particulate organic matter; light reduction; and increased sedimentation. The effects of these four stressors on hard coral colony calcification, tissue growth, symbiosis, reproduction and recruitment were evaluated. The author also looked at some other organisms that affected the abundance of hard corals, and their responses to the above stressors. These included bioeroders, macroalgae, filter feeders, octocorals, disease pathogens and predators. The author concluded that dissolved inorganic nutrients can reduce coral calcification rates, reduce fertilization success, and may promote species of macroalgae that compete for space with corals. Particulate organic matter and turbidity related light limitations have the same effect on heterotrophic filter feeders. Light limitation also reduces coral recruitment. Sedimentation also reduced growth and survival of corals, especially in recruitment and early life stages.

Description of work: Review. Location: None. Keywords: Nutrient, Sediment, Turbidity, Coral

Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

A review of current knowledge on the direct effects of terrestrial runoff, namely: the growth and survival of hard corals, coral reproduction and recruitment, and organisms that interact with coral communities are investigated. Response of each of these is evaluated against water quality parameters: increased dissolved inorganic nutrients, enrichment of organic matter, light reduction from turbidity, and increased sedimentation. Conclusions are that dissolved inorganic nutrients reduce coral calcification and fertilization rates and increase macroalgal abundance. Also, enrichment of particulate organic material enhances feeding rates and growth in some corals giving an advantage to compensate for light reduction (especially in high-flow settings). Lastly, turbidity light limitation reduces gross photosynthesis and reduces coral recruitment, and sedimentation reduces growth and survival of coral depending on species and sediment type. Description of work: Review. Location: None. Keywords: Coral, Sedimentation, Nutrients, Turbidity, Coral reproduction, Recruitment, Light

Fabricius, K. E. and E. Wolanski. 2000. Rapid smothering of coral reef organisms by muddy marine snow. *Estuarine, Coastal and Shelf Science* **50**: 115-120.

A pilot study was presented to demonstrate the rapid detrimental effects on a near-shore coral (*Acropora* sp.) and coral-inhabiting barnacles (subfamily Pyrgomatidae) by suspended estuarine sediment when added to offshore water (oligotrophic: small aggregates) and nearshore waters (nutrient-rich: sediment forms large sticky aggregations of marine snow). The coral and barnacles were positioned in dishes, submerged in seawater and observed microscopically and by video recording. During the off-shore water treatment where aggregates were small in size (~50 micrometers) flocculation was minor and the organisms were able to clean themselves off at low siltation. During the near-shore water treatment, the suspended sticky aggregates of marine snow resulted in the organism's forming thin coats of deposited flocs and vigorously tried to clean themselves. After 5 minutes, the barnacle ceased moving and the coral polyps exuded a thick layer of mucus. Overall, it was suggested that the concentration of suspended mud in the water and extent of stickiness and flocculation can negatively affect reef benthos with only short exposure times.

Description of work: Laboratory. Location: Australia. Keywords: Coral reef, Marine snow, Sediment, Flocculation, Nutrient enrichment, Barnacle

Ferrier-Pages, C., V. Schoelzke, J. Jaubert, L. Muscatine and O. Hoegh-Guldberg. 2001.

Response of a scleractinian coral, *Stylophora pistillata*, to iron and nitrate enrichment. *Journal of Experimental Marine Biology and Ecology* **259**: 249-261.

*Stylophora pistillata* colonies were exposed to 3 week treatments of iron (Fe), nitrate (N), and a combination of the two. The total number of zooxanthellae was significantly higher in colonies exposed to Fe than all other treatments and control groups, as was the total gross photosynthesis. Respiration rates were significantly higher in the colonies exposed to N and FeN combinations.

Mean growth rates were significantly lower in the colonies exposed to Fe and FeN combinations compared to controls. The authors concluded that Fe is toxic to *S. pistillata* even though it increases the total number of zooxanthellae it results in significantly reduced coral growth. The authors suggested that future studies be conducted to determine the effects of iron depletion on photosynthesis and calcification of scleractinian coral because this is likely to occur during a strong El Nino event.

Description of work: Laboratory. Location: Middle East. Keywords: Nutrient, Coral

Fichez, R., M. Adjeroud, U. Bozec, L. Breau, Y. Chancerelle, C. Chevillon, P. Douillet, J. Fernandez, P. Frouin, M. Kulbicki, B. Moreton, S. Ouillon, C. Payri, J. Perez, P. Sasal and J. Thebault. 2005. A review of selected indicators of particle, nutrient and metal inputs in coral reef lagoon systems. *Aquatic Living Resources* **18**: 125-147.

This paper is a review of the literature on indicators of several types of pollution to coral reefs, including particles, nutrients, and metals. The authors suggest that bioindicators be used in conjunction with abiotic indicators in order to more accurately predict the environmental response to inputs of particles, nutrients, and metals. They also suggest that these indicators be "calibrated" to each local system to provide more efficient environmental monitoring tools. This review illustrates a critical information gap in that there is very little scientific background regarding environmental indicators in tropical systems compared to temperate ones.

Description of work: Review. Location: None. Keywords: Coral, Eutrophication, Heavy metal, Nutrient, Sediment

Finkl, C. W. and R. H. Charlier. 2003. Sustainability of subtropical coastal zones in Southeastern Florida: Challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. *Journal of Coastal Research* **19**: 934-943.

The authors address the intense urbanization along southeastern Florida from West Palm Beach to Miami and the effects to the Florida Reef Tract, the Biscayne Aquifer, submarine groundwater discharge, nutrient loading, coastal water quality, and tourism-related activities. Submarine groundwater discharge (SGD) causes an increase in nutrients to the Florida Reef Tract through the Biscayne Aquifer. This aquifer has one of the highest carbonate aquifer transmissivities in the world. Groundwater discharges in Palm Beach County are estimated at  $1,659 \times 10^6$  m<sup>3</sup>/yr. Nutrient fluxes from SGD to the coastal ocean are 5727 metric tons of phosphorous and 414 metric tons of nitrogen per year, while surface water contributions are 197 metric tons for phosphorous and 2471 metric tons for nitrogen per year. It is estimated that SGD is approximately 133% of surface water discharge. The authors suggest that the major source of these nutrients is sugar cane farming and that current approaches to remedy the situation will fail because they are focused on treating the symptoms not the cause of the problem. Topics addressed include: sustainability of beach systems and of agro-urban coastal environments; and the status quo and sustainability prognosis.

Description of work: Review. Location: Southeastern Florida. Keywords: Inlet, Environmental integrity, Submarine Groundwater discharge, Nutrient loading, Water quality, Remediation, Coastal Management, N, P

Finkl, C. W. and S. Krupa. 2003. Environmental impacts of coastal-plain activities on sandy beach systems: Hazards, perception and mitigation. *Journal of Coastal Research* **35**: 132-150.

A review of submarine groundwater discharge (SGD) as a source of nutrients to coastal areas in the Caribbean and Florida. The authors state that agricultural and urban activities lead to pollution of the surficial aquifers which in turn pollute the groundwater. The authors suggest that this is a significant source of nutrients to the nearshore coastal regions and that it is steadily degrading the water quality. Increased concentrations of nutrients delivered via SGD can cause algal blooms and the reduction of water quality could lead to beach closings and loss of revenue in the future if left unchecked. Nutrient pollution from SGD is not easily visible and is often overlooked by the public in favor of preventing more obvious problems such as beach erosion. The authors suggest that seepage meter tests be conducted in order to quantify the problem as well as to draw attention to it.

Description of work: Review. Location: Caribbean and Florida. Keywords: SGD, Nutrients

Fleury, B. G., J. C. Coll, P. W. Sammarco, E. Tentori and S. Duquesne. 2004. Complementary (secondary) metabolites in an octocoral competing with a scleractinian coral: effects of varying nutrient regimes. *Journal of Experimental Biology and Ecology* **303**: 115-131.

As a part of the larger project, "Enrichment of Nutrients on Coral Reefs Experiment" (ENCORE) on the Great Barrier Reef (GBR), this study looked at competitive interactions between a hard and soft coral, with respect to space and nutrient regimes. Experiments were carried out on 12 micro-atolls in the One Tree Island lagoon for one year. The stress response of *Sarcophyton ehrenbergi* to physical contact with *Pocillopora damicornis* and under different nutrient regimes was analyzed. Stress was determined by measuring the tissue concentration of sarcophytoxide and wax esters in the soft corals. Results from the analysis of 104 pooled soft coral tissue samples revealed that elevated N and P concentrations increased sarcophytoxide production in all specimens while N+P treatments had no effect. Sarcophytoxide levels were higher, and concentrations of fatty esters were lower in all soft corals placed in contact with the scleractinian coral *P. damicornis*. The findings indicated that competition for space between a hard and soft coral as well as nutrient fluctuations changed tissue concentrations of certain metabolites and reduced stored energy reserves of soft corals.

Description of work: Field. Location: Australia. Keywords: Coral, Nutrient, Competition

Fokiel, P. L., E. K. Brown, A. Friedlander, S. K. Rodgers and W. R. Smith. 2004. Hawaii Coral Reef Assessment and Monitoring Program: Spatial patterns and temporal dynamics in reef coral communities. *Pacific Science* **58**: 159-174.

The Coral Reef Assessment and Monitoring Program (CRAMP) was established in 1999 to describe spatial and temporal variations in Hawaiian coral reefs in relation to natural and anthropogenic factors. This article reports the findings of the initial 3 year study period. The study examined 30 locations around the state. Permanent monitoring stations were established, one shallow and one deep, at each of the sites. Qualitative data on coral cover and diversity,

macroalgae abundance, and fish populations was assembled from each site. This descriptive data was combined with the following ancillary variables: total population values; total area of adjacent watersheds; mean annual rainfall; offshore wave height; geologic age of the associated island and a ranking of the current level of reef management protection. Analysis of the data identified 6 major natural influences on coral reef community structure (depth, wave height, wave direction, island age, rugosity and sediment grain size). The dominant trend in anthropogenic influences was identified as extensive sedimentation resulting from human population activity in adjacent catchments.

Description of work: Field. Location: Hawaii. Keywords: CRAMP, Coral, Nutrient, Sediment

Furnas, M., A. Mitchell, M. Skuza and J. Brodie. 2005. In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. *Marine Pollution Bulletin* **51**: 253-265.

A review of phytoplankton growth rates in the Great Barrier Reef (GBR) found that ambient concentrations of N & P were not limiting. The dominant species was found to have potential population doubling rates of <1 day. Estimates of N & P demand by phytoplankton in nearshore waters showed that daily water column nutrient demand far exceeds the average daily amount supplied by benthic mineralization, river input, upwelling events and sewage discharges combined. The fact that nutrients are supplied in pulse events (river plumes) allows for the possibility that for short durations the input amounts may exceed phytoplankton demand. Nutrient limitation and grazing processes accounted for the lack of phytoplankton blooms in GBR waters. Ambient concentrations of N & P remained relatively constant because mineralization and uptake rates were balanced. In general only a small percentage of nutrients from nutrient pulse events reached the reefs or other benthic communities of the GBR. The bulk of the inorganic nutrient load were consumed by phytoplankton and converted to organic forms as they were passed up the food chain. These organic forms of nutrients were often dispersed over large areas and directly responsible for nutrient effects on benthic communities. Because of the rapid uptake of inorganic nutrients, measurements of dissolved inorganic nitrogen or dissolved inorganic phosphorous alone were not suitable for estimating nutrient availability. These values must be combined with accurate measurements of nutrient inputs, consumption, and turnover rates to quantify nutrient flow through the food chain to the point where it affects coral reefs.

Description of work: Review. Location: Australia. Keywords: Nutrient, DIN, DON, DIP, SGD, Upwelling, Mineralization, Benthic, Phytoplankton, Nitrogen, Phosphate

Garrison, V. H., E. A. Shinn, W. T. Foreman, D. W. Griffin, C. W. Holmes, C. A. Kellogg, M. S. Majewski, L. L. Richardson, K. B. Ritchie and G. W. Smith. 2003. African and Asian dust: From desert soils to coral reefs. *Bioscience* **53**: 469-480.

The authors present an overview of the atmospheric transport of African and Asian dust. They review background information and research which address airborne microorganisms, coral diseases, and atmospheric transport of chemical contaminants as well as suggest mechanisms and strategies of investigation into these topics. The authors hypothesize that dust transport from Africa and Asia to the Americas is a significant factor negatively affecting coral and downstream

communities. In addition, it is suggested the quantity of dust has increased and its composition has changed to include synthetic organic chemicals, anthropogenic pollutants, microorganisms, macro and micronutrients, and trace metals.

Description of work: Review. Location: None. Keywords: Coral, Dust, Disease, Nutrient, Pollutant, Microorganism

Greiner, R., A. Herr, J. Brodie and D. Haynes. 2005. A multi-criteria approach to Great Barrier Reef catchment (Queensland, Australia) diffuse-source pollution problem. *Marine Pollution Bulletin* **51**: 128-137.

This review presents a multi-criteria tool for assessing the impact of diffuse-source pollution to the Great Barrier Reef (GBR) from the river basins that drain into it. Four ratings (low, medium, medium-high, or high impact) for each river basin are compared against four criteria (potential impact of diffuse-source pollution, potential social impact of pollution prevention, potential economic impact of pollution, and development pressures), creating a profile for the basins enabling prioritization of management between them. Results provide support for the Reef Water Quality Protection Plan, released in October 2003. This plan aims to reduce discharge of sediment, nutrients, and other diffuse-source loads of potential impact as well as prioritize management actions.

Description of work: Review. Location: Australia. Keywords: Coral, Management, Multi-criteria method, Land-based pollution, Water quality, Policy, Nutrient

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Hoegh-Guldberg, O., L. Muscatine, C. Goiran, D. Siggaard and G. Marion. 2004. Nutrient-

induced perturbations to  $^{13}\text{C}$  and  $^{15}\text{N}$  in symbiotic dinoflagellates and their coral hosts. *Marine Ecology Progress Series* **280**: 105-114.

This 2 year study was a part of the Enrichment of Nutrients on Coral Reefs Experiment (ENCORE). Nutrient pulses of either N, P, or N+P combined were added to 12 patch reefs twice daily. Specifically, this study examined the effects of long-term eutrophication on the  $^{13}\text{C}$  and  $^{15}\text{N}$  values in *Pocillopora damicornis* and *Heliofungia actiniformis*.  $^{13}\text{C}$  and  $^{15}\text{N}$  values in the three coral compartments (skeleton, coral tissue and zooxanthellae), were measured. Analysis of the  $^{13}\text{C}:$  $^{15}\text{N}$  ratios revealed that coral samples from the N and N+P treated reefs had the lowest  $^{13}\text{C}:$  $^{15}\text{N}$  values and that samples from the P treated reefs had the highest.  $^{13}\text{C}$  values differed by compartment but not by nutrient regime and skeletal material contained the highest values in both species.  $^{15}\text{N}$  values were strongly influenced by nutrient treatment type. Coral tissue and zooxanthellae exhibited the largest response with highest  $^{15}\text{N}$  values in the samples from the P treated reefs and lower values in the N and N+P treated reefs.

Description of work: Field. Location: Australia. Keywords: Nutrient, Coral, Eutrophication

Holmes, K., E. Edinger, Hariyadi, G. Limmon and M. Risk. 2000. Bioerosion of live massive corals and branching coral rubble on Indonesian coral reefs. *Marine Pollution Bulletin* **40**: 606-617.

Bioerosion was measured in live massive coral and branching coral rubble from two regions in Indonesia and then compared to control sites. Bioerosion in both live coral and coral rubble was significantly higher where there was evidence of eutrophication compared to controls. Boring sponges (*Cliona*, *Cliothosa*, *Siphonodictyon*) were the main bioeroding organisms present in both live coral and coral rubble. The authors concluded that bioerosion is positively correlated with indicators of eutrophication. The authors suggested that measuring bioerosion rates on coral rubble is a rapid and inexpensive indicator of eutrophication stress on coral reefs.

Description of work: Field. Location: Indo-Pacific. Keywords: Nutrient, Eutrophication, Coral

Hu, C., F. Muller-Karger, G. Vargo and M. Neely. 2004. Linkages between coastal runoff and the Florida Keys ecosystem: A study of a dark plume event. *Geophysical Research Letters* **31**: 1-4.

Study of a dark water plume event off the coast of southern Florida using satellite data, rain and river gauges, and ship surveys. It was concluded that the plume was caused by excess rainfall throughout the months of June and August, 2003. The plume was characterized by high amounts of dissolved organic matter and extensive phytoplankton blooms which possibly included *Karenia brevis* cells in the upstream part of the plume. Using a model, the total nitrogen content necessary to sustain the bloom was calculated at concentrations in excess of  $2.3 \times 10^7$  mol. The total phosphorus was calculated in excess of  $1.5 \times 10^6$  mol. The authors suggested that the nutrients and dissolved organic matter necessary to support the observed phytoplankton bloom were supplied via coastal and river runoff.

Description of work: Field. Location: Florida Keys. Keywords: Coastal ocean processes, Current, Nutrient



Hughes, T., A. M. Szmant, R. Steneck, R. Carpenter and S. Miller. 1999. Algal blooms on coral reefs: What are the causes? *Limnology and Oceanography* **44**: 1583-1586.

This is a critique of the logic, analysis, and accuracy of the data presented by Lapointe (1997). The authors state that the claim that macroalgal blooms on Caribbean coral reefs are the result of eutrophication of the reef waters beyond a definitive threshold level was not valid because coral reefs are known to flourish in various nutrient regimes, and Lapointe (1997) did not show a temporal correlation between eutrophication patterns and macroalgal blooms, whereas the timing of events such as the *Diadema antillarum* die off correlates well with the region wide degradation of Caribbean coral reefs. Lapointe only provided limited data on levels of nutrient input from fresh water seepage, and his theory that the mass mortality of *Diadema* occurred years before the increased abundance in macroalgae contradicted extensive literature on this subject. The physiological and biochemical data for C:N:P, C:N and C:P ratios was not interpreted correctly. Lapointe also used unrealistically high nutrient levels in his experiment and did not give enough consideration to upwelling events.

Description of work: Comment. Location: None. Keywords: Coral, Nutrient

Kim, K., P. D. Kim, A. P. Alker and C. D. Harvell. 2000. Chemical resistance of gorgonian corals against fungal infections. *Marine Biology* **137**: 393-401.

*Aspergillus sydowii*, a disease caused by a fungal pathogen, was studied. Corals were experimentally evaluated to investigate natural mechanisms of disease resistance. Antifungal compounds were effective in disease prevention when found in high concentrations and high potency. A specificity of *Aspergillus sydowii* for *Gorgonia ventalina* and *G. flabellum* may indicate a heightened sensitivity to changes in water quality which can compromise disease resistance. The impact of this pathogen was higher on reefs with high nutrient levels and turbidity which indicated water quality as an important factor in host-pathogen interactions. Description of work: Laboratory. Location: Florida. Keywords: Coral disease, *Aspergillus sydowii*, Coral pathogen, Disease resistance, Nutrients, Turbidity, Water Quality

Koop, K., D. Booth, A. Broadbent, J. Brodie, D. Bucher, D. Capone, J. Coll, W. Dennison, M. Erdman, P. Harrison, O. Hoegh-Guldberg, P. Hutchings, G. B. Jones, A. W. D. Larkum, J. O'neil, A. Steven, E. Tentori, S. Ward, J. Williamson and D. Yellowlees. 2001. ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. *Marine Pollution Bulletin* **42**: 91-120.

The Enrichment of Nutrients on Coral Reefs Experiment (ENCORE) was conducted on 12 patch reefs, in the One Tree Island lagoon, over a period of 2 years. The effects of nutrient enrichment on five major groups of coral reef fauna (stomatopods, fish, reef-building corals, soft corals and giant clams) were studied, as well as the effects on macroalgae, epilithic algal community and rhodoliths. Effects on reproduction, mortality rates, growth rates, lipid levels in acroporid corals were also examined. Sarcophytotoxins and fatty ester levels were measured in the soft coral *Sarcophyton ehrenbergi*. There was no significant response in the epilithic algal community or

rhodolith species. The responses of macroalgae varied by species. Other parameters observed were the effects on zooxanthellae, bioerosion rates and microbial nitrogen transformations in sediments. Coral reproduction was the most sensitive indicator to increased nutrients.

Description of work: Location: Australia. Keywords: Coral, Nutrient

Kuntz, N. M., D. I. Kline, S. A. Sandin and F. Rohwer. 2005. Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species. *Marine Ecology Progress Series* **294**: 173-180.

Corals were exposed to different organic carbon sources and various nutrient regimes and examined for pathological responses and rates of mortality. The results of the 30 day experiment showed species-specific as well as carbon-specific responses and mortality rates. Chronic exposure to organic carbons produced increased mortality rates over the course of the experiment. Responses to these stressors varied among species, and therefore are not considered useful for assessing coral health. Increased levels of nutrients caused various pathological responses but had no effect on coral mortality rate. In general, the impact of multiple chronic stressors on corals increased exponentially over time.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Nutrient

Kuta, K. G. and L. L. Richardson. 2002. Ecological aspects of black band disease of corals: relationships between disease incidence and environmental factors. *Coral Reefs* **21**: 393-398.

Salinity, water depth, water temperature, nitrate, nitrite, ammonium, soluble phosphate, total phosphate, turbidity, coral diversity, and percent coral cover were measured at 190 sites on 12 patch reefs. Twenty-one of the sites contained a colony with active black band disease and 169 sites contained healthy colonies susceptible to the disease. Water temperature, depth, coral diversity, and concentrations of orthophosphate and nitrite showed statistically significant relationships with the disease.

Description of work: Field. Location: Florida. Keywords: Black band disease, Coral reef ecology, Coral reef health, Salinity, Temperature, Nutrients

Lapointe, B., P. Barile, M. Littler and D. Littler. 2005a. Macroalgal blooms on southeast Florida coral reefs II. Cross-shelf discrimination of nitrogen sources indicates widespread assimilation of sewage nitrogen. *Harmful Algae* **4**: 1106-1122.

Macroalgal samples were collected from three different depths along seven transects from Jupiter to Deerfield beach, Florida, USA. Sampling was done over two periods, one during a drought and one during summer wet season to reflect changes in storm water runoff and upwelling patterns. The tissue samples were analyzed for  $N^{15}$ .  $N^{15}$  values did not vary between samplings and were significantly higher on inshore shallow reefs compared to mid and deep reefs.  $N^{15}$  values were also higher in the southern portion of the study area, this was believed to have been

caused by the areas proximity to an outfall of sewage wastewater. The authors suggest that N sources from land-based sewage are more important than upwelled N to these macroalgae. Description of work: Field and Laboratory. Location: Florida. Keywords: Coral, Algae, Nutrient

Lapointe, B., P. Barile, M. Littler, D. Littler, B. Bedford and C. Gasque. 2005b. Macroalgal blooms on southeast Florida coral reefs I. Nutrient stoichiometry of the invasive green alga *Codium isthmocladum* in the wider Caribbean indicates nutrient enrichment. *Harmful Algae* **4**: 1092-1105.

Samples of *Codium isthmocladum* were taken from several reef sites in southeast Florida and compared to samples taken from the Caribbean. All samples were analyzed for tissue C:N:P ratios. Results indicated that the Florida samples contained significantly higher P in tissues at 0.06% compared to 0.04% in the Caribbean samples. Florida samples also had lower C:N, C:P, and N:P ratios compared to Caribbean samples. Near-bottom water samples also showed increased concentrations of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  in southeast Florida compared to the Caribbean. The authors concluded that the recent blooms of *C. isthmocladum* in southeast Florida were caused by land-based nutrient pollution.

Description of work: Field and Laboratory. Location: Florida and Caribbean. Keywords: Coral, Algae, Nutrient

Lapointe, B. E. 1999. Simultaneous top-down and bottom-up forces control macroalgal blooms on coral reefs (reply to the comment by Hughes et al.). *Limnology and Oceanography* **44**: 1586-1592.

Hughes et al. (1999), presented arguments against three aspects of the original study by Lapointe (1997): 1) a grazing hypothesis alone is a more accurate explanation for algal blooms on Caribbean reefs; 2) the nutrient threshold value used to support the relative-dominance model was incorrect; 3) the biochemical assay data did not support the conclusions. Lapointe states that he did recognize the effects of grazing and nutrient availability on macroalgal blooms in his 1997 paper. Lapointe clarified that his study was a field test of the nutrient threshold model, not a test of the hypothesis that reefs had exceeded a eutrophication threshold value. Finally, the author pointed out that he did not use a regression analysis with only two points to identify trends in nutrient concentration. In fact the data used was a time series of measurements compiled from three independent studies.

Description of work: Reply. Location: None. Keywords: Coral, Bottom-up, Top-down, Nutrient

Lapointe, B. E. 2004. Anthropogenic nutrient enrichment of seagrass and coral reef communities in the Lower Florida Keys: discrimination of local versus regional nitrogen sources. *Journal of Experimental Marine Biology and Ecology*. **308**: 23-58.

$^{15}\text{N}$  data was used to assess the concentrations of nutrients generated from local sources in the Florida Keys. The study looked at DIN,  $\text{NH}_4^+$ , SRP,  $\text{NO}_3^-$ , and chlorophyll a concentrations. The water samples were taken from shallow seagrass and coral reef communities. Results

support previous work that used time-series measurements of salinity, temperature and nutrients to show land-based runoff as a major source of nutrients in coastal waters. The author concluded that land-based nutrient enrichment caused macroalgae blooms and an increase in seagrass epiphytes. Physical forcing of land-based wastewater was also discussed.

Description of work: Field. Location: USA. Keywords: Sewage, DIN, N, P, Runoff, Nutrient, Coral,  $^{15}\text{N}$  stable isotope

Lapointe, B. E. 2005. Draft Final Report - Distribution and Ecology of Invasive and Harmful Macroalgal Blooms on Coral Reefs off Southeast Florida. 23.

The distribution of various species of invasive macroalgae in nearshore waters was examined. The study area included a siliciclastic environment to the north and a sub-tropical carbonate-rich environment to the south. Historically, invasive species of macroalgae have not thrived in subtropical waters because of the natural P-limited nature of carbonate-rich environments. Recent latitudinal shifts in harmful algal blooms from north to south, may be the result of a biogeochemical transition of the southern part of the study area to a less P-limited carbonate-rich environment. The data suggest, many harmful algal bloom (HAB) species were able to migrate into the southerly carbonate-rich waters because of a steady supply of anthropogenically produced P. Stable isotope  $^{15}\text{N}:$  $^{14}\text{N}$  values in macroalgal tissues from nearshore waters indicate anthropogenic N inputs. There is a lack of knowledge of the geographic or seasonal distribution, biochemical composition, or ecology of these HABs. The 2004 hurricanes physically removed most of the HABs, however reformation of *Lyngbya* spp. blooms were observed soon after the hurricane season ended. Macroalgal tissue phosphate and  $^{15}\text{N}:$  $^{14}\text{N}$  values increased latitudinally from South to North while  $^{13}\text{C}$  values varied throughout the study area.

Description of work: Report. Location: Florida. Keywords: Nutrient, Coral, N, P, Injection wells

Lapointe, B. E., P. J. Barile, C. S. Yentsch, M. M. Littler, D. S. Littler and B. Kakuk. 2004. The relative importance of nutrient enrichment and herbivory on macroalgal communities near Norman's Pond Cay, Exuma Cays, Bahamas: a "natural" enrichment. *Journal of Experimental Biology and Ecology* **298**: 275-301.

A unique ecosystem in the Bahamas, with a well defined natural nutrient gradient, was examined with respect to macroalgal biomass and species composition. Additionally, grazer exclusion cages were used to examine the relative importance of herbivory and any possible relation to macroalgal tissue nutrient biochemistry. Samples were collected along a 100 m transect from a mangrove channel opening to an offshore patch reef. Macroalgal samples were analyzed for biomass and C:N:P ratios. Two rhodophytes, *Laurencia intricata* and *Digenea simplex*, dominated the macroalgal community at the channel opening and the inner Algal Halo. The chlorophytes *Microdictyon marinum* and *Cladophora catenata* dominated the outer Algal Halo community. Selective grazing was observed in the higher DIN macroalgal community by gastropods and herbivorous fish, suggesting a preference for higher quality nitrogen. Analysis of the data showed that herbivory had little effect on the biomass of *D. simplex* while nutrient enrichment had a significant effect. *L. intricata* was significantly effected by both nutrient concentration and herbivory. Overall nutrients had a greater effect on macroalgal biomass than

herbivory.

Description of work: Field. Location: Caribbean. Keywords: DIN, C:N:P, Coral, Nutrient

Lapointe, B. E. and M. W. Clark. 1992. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. *Estuaries* **15**: 465-476.

The effects of nutrient inputs from septic tank leachant were analyzed in the Florida Keys coastal zone. Nutrient levels along a land-sea gradient across four ecosystems from inshore to offshore waters in the Florida Keys were measured. The ecosystems examined were, canals, seagrass meadows, patch reefs and offshore bank reefs. The authors found that septic tank leachant was increasing N and P concentrations to nearshore waters via manmade canal systems. Elevated  $\text{NH}_4^+$  concentrations were found in the canals and seagrass meadows but decreased with distance from shore. Soluble reactive phosphate and particulate phosphate concentrations followed the same pattern. Dissolved oxygen values increased with distance from land. During the summer, hypoxic conditions were observed at several Florida Bay stations. The study suggested that nutrient enriched submarine ground water discharge was intensifying coastal water eutrophication.

Description of work: Field. Location: Florida. Keywords: Eutrophication, Coral, Nutrient, SGD

Lapointe, B. E., M. M. Littler and D. S. Littler. 1987. A comparison of nutrient-limited productivity in macroalgae from a Caribbean barrier reef and from a mangrove ecosystem. *Aquatic Botany* **28**: 243-255.

The dominant macroalgae populations from naturally nutrient rich waters (mangrove ecosystems) and from oligotrophic waters (coral reefs) were analyzed in order to determine the limiting nutrient, N or P, for each system. Enrichment assays were conducted in the lab using varying concentrations of  $\text{NH}_4^+$  and P. Changes in productivity in *Dictyota* and *Halimeda sp.* from a coral reef population and a mangrove island population were measured. *Dictyota* specimens from the coral reef population exhibited a three fold increase in productivity in the enrichment assays relative to those specimens from the mangrove island. Uptake of P was greater than that of N for both populations. *Halimeda* specimens from both populations only responded to the increased concentration of N with negligible uptake of P.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Nutrient, N, P

Lapointe, B. E. and W. R. Matzie. 1996. Effects of stormwater nutrient discharges on eutrophication processes in nearshore waters of the Florida Keys. *Estuaries* **19**: 422-435.

The hypothesis that rainfall causes pollution pulse events in coastal waters from land based septic systems was tested. Chlorophyll a, dissolved oxygen, N and P concentrations were recorded at 6 stations along a eutrophication gradient in the lower Florida Keys. Salinity and tide data was also included in the analysis. The  $\text{NH}_4^+$ , DO, Chl-a and salinity data “are above threshold levels known to mark the decline of coral reefs”, and demonstrate the need for advanced wastewater treatment.

Description of work: Field. Location: Florida. Keywords: Coral, Dissolved Oxygen, Nutrient

Lapointe, B. E. and J. Oconnell. 1989. Nutrient-enhanced growth of *Cladophora prolifera* in Harrington Sound, Bermuda: Eutrophication of a confined, phosphorus-limited marine ecosystem. *Estuarine, Coastal and Shelf Science* **28**: 347-360.

Growth rate of the green algae *Cladophora* was measured to test the hypothesis that productivity is significantly enhanced by nutrient rich groundwater seepage. In-situ pore waters under algal mats were found to have reduced salinities, elevated levels of  $\text{NH}_4^+$  and high N:P ratios. The study utilized a flowing-seawater culture system to directly measure the nutrient dependence of *Cladophora* productivity. The data showed that enhanced growth rates were the result of N rich groundwater seepage and the efficient utilization of organo-phosphorus compounds by *Cladophora*.

Description of work: Laboratory. Location: Caribbean. Keywords: Nutrient, Coral, N, P, Groundwater

Larned, S. T. 1998. Nitrogen- versus phosphorus-limited growth and sources of nutrients for coral reef macroalgae. *Marine Biology* **132**: 409-421.

Macroalgae growth in Kaneohe Bay was examined in order to determine if it was a nitrogen or phosphorus limited community. Laboratory enrichment studies were carried out on nine species of macroalgae. The authors tested three alternative hypothesis: 1) that phosphorus limits macroalgae productivity in the bay; 2) that nitrogen is generally limiting; 3) that nutrient limitation is species specific. Dissolved inorganic nitrogen:phosphate ratios from water column samples were compared with total nitrogen:total phosphate ratios from tissue samples of macroalgae from the bay. The authors found that in 8 out of 9 macroalgae species inorganic nitrogen was the limiting nutrient. Analysis of the data suggested that the Kaneohe Bay system could not be classified as a whole but that each species in the bay may be N or P limited. The distribution of macroalgae species is determined by the benthic nutrient concentrations and water flow. At high energy locations nutrients in the water column are the primary source of N & P. At low energy sites, sediments appear to supply nutrients to macroalgae necessary to sustain growth.

Description of work: Laboratory. Location: Hawaii. Keywords: Nutrient, Coral, N, P

Leichter, J. J., H. L. Stewart and S. L. Miller. 2003. Episodic nutrient transport to Florida coral reefs. *Limnology and Oceanography* **48**: 1394-1407.

Internal tidal bores have been discovered to bring cool nutrient rich water to the coral reef slopes along the Florida Keys. Hydrographic, nutrient and algal data from Conch Reef were compared to data from another study monitoring tidal bore activity along the Florida Keys reef tract. Nutrient concentrations in tissue samples from the macroalgae *Codium isthmocladum* were used to evaluate biological responses to nitrogen pulses associated with the tidal bores. The data

suggest tidal bores supply N input along the reef tract at  $1.68 \times 10^3$  to  $6.1 \times 10^4$  kg per bore. Estimates of P inputs ranged from  $3.7 \times 10^2$  to  $10.0 \times 10^3$  kg per bore. Total nutrient load to the coral reef tract could be 20 - 40 times greater than the inputs to near-shore waters from anthropogenic sources and storm water run-off.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral, Upwelling

Lipp, E. K., J. L. Jarrell, D. W. Griffin, J. Lukasik, J. Jacukiewicz and J. B. Rose. 2002. Preliminary evidence for human fecal contamination in corals of the Florida Keys, USA. *Marine Pollution Bulletin* **44**: 666-670.

The coral surface microlayer (CSM) was examined to determine if it may provide a useful measure of fecal coliform and enterococci concentrations. Surface water grab samples were taken from four sites in the middle Keys and cultured for enteroviruses. Fifteen mucus samples were also taken from corals at each site. Bacteria levels were much higher in the CSM samples than the associated water column samples. The authors suggested that due to the high rate of decay of bacterial indicators in the water column that the CSM may be a more accurate sampling medium to detect the presence of fecal coliform in coral reef waters.

Description of work: Field. Location: Florida. Keywords: Coral, Nutrient, Fecal Coliform bacteria

Loya, Y., H. Lubinevsky, M. Rosenfeld and E. Kramarsky-Winter. 2004. Nutrient enrichment by in situ fish farms at Eilat, Red Sea is detrimental to coral reproduction. *Marine Pollution Bulletin* **49**: 344-353.

The effects of excess nutrients from fish farms, on the reproductive effort of the brooding coral *Stylophora pistillata* were studied. 20 colonies of *S. pistillata* were placed 150 m west of a fish farm and 20 colonies were placed 8 km southwest of the farm. Histopathological analysis of the corals included a comparison of percentage of polyps containing oocytes and testes, average oocyte size, and percentage of oocytes that reached reproductive size. Data was collected throughout the reproductive season. Results revealed a negative effect on all parameters for the coral group adjacent to the farm.

Description of work: Field. Location: Middle East. Keywords: Coral, Nutrient, Eutrophication

Marubini, F. and B. Thake. 1999. Bicarbonate addition promotes coral growth. *Limnology and Oceanography* **44**: 716-720.

This study tested if the supply of dissolved inorganic carbon (DIC) in seawater limits calcification. Nubbins of the hermatypic coral *Porites porites* cultured in seawater were compared to nubbins of the same coral cultured in DIC-enriched (+2 mM) seawater. The authors also tested if limitation of calcification by nitrogen can be compensated for by DIC enrichment. In the case of the DIC-enriched seawater, skeletal growth rate of the coral doubled. Nitrate or

ammonium addition (20 micromoles) caused a significant reduction in coral growth. However, when seawater with the extra bicarbonate was supplemented with nitrogen, no growth depression occurred. Overall, the dissolved inorganic carbon content of the ocean limited coral growth, this limitation was exacerbated by the presence of nitrate and ammonium, and adding DIC increased coral calcification rates and protected against nutrient enrichment.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral growth, Calcification, Dissolved inorganic carbon, Nutrient enrichment

McClanahan, T., R. Steneck, D. Pietri, B. Cokos and S. Jones. 2005. Interaction between inorganic nutrients and organic matter in controlling coral reef communities in Glovers Reef Belize. *Marine Pollution Bulletin* **50**: 566-575.

Responses to increases in inorganic nutrients, organic matter and a combination of the two were studied in algae, coral, and some small fish. The number of Wrasse fish were not significantly affected by any of the treatments. Parrotfish and damselfish numbers decreased with the addition of organic matter compared to the other treatments and a control. Algal biomass was highest in treatments of combined inorganic nutrients/organic matter. Coral mortality did not occur with any treatment, however, color changes were observed. Up to 18% of *Porites furcata* tissues darkened in response to all treatments. *Diploria labyrinthiformes* however, paled in approximately 10% of tissues after 35 days in all treatments as well as in control groups. There was also some darkening of this species after 14 days in organic and combined treatments. The authors suggest that there is a complicated interaction between herbivory, nutrients, and organic matter affecting coral reefs

Description of work: Field. Location: Caribbean. Keywords: Coral, Nutrient

McCook, L. J. 1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. *Coral Reefs* **18**: 357-367.

Nitrification alone can not cause a coral to macroalgal phase shift on coral reefs. At the time of publication there was not enough evidence to support this bottom-up theory with respect to management decisions. Six possible alternative causes of coral reef degradation were discussed: herbivore decline; reduction in topographic complexity; indirect effects of sediment and nutrients; "supply-side" effects; combined effects of natural disturbances and eutrophication; and synergistic effects of multiple factors. Subtle disjointed anthropogenic impacts on coral reefs from adjacent land may be difficult to prove and lead to incorrect management decisions. Management efforts to reduce nutrient impacts to coral reefs without protection of herbivores will fail to restore reef quality. Correct identification of the cause of reef degradation is critical to the success of coral reef rehabilitation strategies. The "nutrient threshold" theory of classifying reefs as eutrophic once a discrete nutrient concentration value is measured in the water column does not hold up to critical scrutiny. The author recommended that future management decisions should focus on protecting and or restoring herbivore populations and reducing terrigenous runoff of sediment and nutrients.

Description of work: Review. Location: Australia. Keywords: Nutrients, Eutrophication, Coral



Meyer, J. L. and E. T. Schultz. 1985. Migrating haemulid fishes as a source of nutrients and organic matter on coral reefs. *Limnology and Oceanography* **30**: 146-156.

Juvenile grunts were found to aggregate over coral colonies during the day and forage in seagrass beds at night. Groups of *Haemulon flavolineatum* and *Haemulon plumieri* were captured and daily excretion rates of N and P were measured under laboratory conditions. The data was used to calculate the size specific rate of nutrient excretion. Feces were analyzed for bacterial colonization and leaching rates. Half of the total daily excretion occurred in the first four hours after returning to the coral colonies and resulted in a short term doubling of the amount of  $\text{NH}_4^+$  available in the coral reef waters. P input was calculated at a rate of 22 mol N:1 mol P, which is consistent with the N:P ratio found in the coral tissues. The bioavailability of P however was restricted because the majority of the nutrient was excreted in particulate form. The rates of nutrient and organic matter input from schools of grunts to coral colonies were calculated to be equal to or greater than any other source of nutrients.

Description of work: Laboratory. Location: Caribbean. Keywords: Nutrient, Coral, N, P

Miller, M. W., M. E. Hay, S. L. Miller, D. Malone, E. E. Sotka and A. M. Szmant. 1999. Effects of nutrients versus herbivores on reef algae: A new method for manipulating nutrients on coral reefs. *Limnology and Oceanography* **44**: 1847-1861.

This study evaluated the effectiveness of a new nutrient diffusing substrate technique. The overall objective was to compare the results of in-situ enrichment and herbivory experiments with two previously proposed models (Relative Dominance Model, Littler et. al. (1997) & Nutrient Threshold model, Bell (1992) and Lapointe (1997)). The experiment was conducted on an offshore reef in the Florida Keys reef tract. A mix of fertilizer enriched and unenriched (control) units were affixed to reefs with either partial or complete herbivore exclusion cages. Macroalgal abundance and biomass did not differ between nutrient enriched units and the control units. There was significantly greater algal biomass in the units with complete herbivore exclusion cages than those left exposed to herbivory. The results supported the relative dominance model with some exceptions, notably that increased nutrients were required for macroalgae over abundance on coral reefs. The authors conclude that the macroalgae in their study area was nutrient replete. This may be explained by the concept that given adequate water motion and turbulence macroalgal growth can be sustained in oligotrophic systems.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral

Moss, A., J. Brodie and M. Furnas. 2005. Water quality guidelines for the Great Barrier Reef World Heritage Area: a basis for development and preliminary values. *Marine Pollution Bulletin*. **51**: 76-88.

This paper discussed how to establish local and regional water quality guidelines from existing federal guidelines. Nutrients, sediments and agricultural chemical impacts from adjacent

catchments are addressed with respect to two types of water quality guidelines, pressure and biological response indicators. Region specific guidelines based on the methodologies of ANZECC guidelines were proposed. Water temperature,  $^{15}\text{N}$ , and diuron were specifically mentioned. It was concluded that currently there are not adequate indicators to determine if biological impacts on reefs are due to water quality alone in the GBRWHA. The authors made the following recommendations: develop indicators using a mix of stressors and compile adequate data sets to establish guidelines.

Description of work: Review. Location: Australia. Keywords: Nutrient, Sediment, Herbicide, Pesticide, Coral

Muller-Parker, G., C. Cook and C. D'Elia. 1994a. Elemental composition of the coral *Pocillopora damicornis* exposed to elevated seawater ammonium. *Pacific Science* **48**: 234-246.

C, N, and P were measured in *Pocillopora damicornis* and its zooxanthellae after exposure to 20  $\mu\text{M}$  and 50  $\mu\text{M}$  ammonium enrichments. Total N and P in zooxanthellae increased significantly with exposure to 20  $\mu\text{M}$  ammonium over an 8 week period. The authors suggested the increase in N was due to both increased density of zooxanthellae and increased N per cell, while the increase in P was due solely to increased zooxanthellae density. The amount of C in zooxanthellae was not effected by exposure to 20  $\mu\text{M}$  ammonium. In the 50  $\mu\text{M}$  ammonium treatments both C and P in zooxanthellae declined significantly over time. C, N and P values for the coral itself were not affected by the treatments.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Ammonium, Nutrient

Muller-Parker, G., L. McCloskey, O. Hoegh-Guldberg and P. McAuley. 1994b. Effect of ammonium enrichment on animal and algal biomass of the coral *Pocillopora damicornis*. *Pacific Science* **48**: 273-283.

This study confirmed the hypothesis that growth of tropical zooxanthellae in corals is nitrogen limited. Colonies of *Pocillopora damicornis* were exposed to 20  $\mu\text{M}$  or 50  $\mu\text{M}$  ammonium for periods of 2 to 8 weeks. Density of zooxanthellae was measured in each colony. Increased density of zooxanthellae was found within the first 2 weeks of exposure to nitrogen concentrations of 20  $\mu\text{M}$ , and continued to increase with time. No significant increase was found with respect to time in colonies exposed to 50  $\mu\text{M}$  ammonium, suggesting that this concentration may be stressful to the coral.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Nutrient

Nixon, S. W. 1995. Coastal marine eutrophication: A definition, social causes, and future concerns. *Ophelia* **41**: 199-219.

The history and inconsistency of the use of the word "eutrophication" was examined. A unifying definition of eutrophication as "an increase in the rate of supply of organic matter to an ecosystem" was proposed for future use. Two aspects of the nutrient input problem, emission

and transmission, were discussed on a global scale. Nutrient emissions, mainly N and P, were mostly from combustion of fossil fuels and use of fertilizers. The increasing human population world wide will increase the magnitude of both of these nutrient sources. Transmission of nutrients will also increase as a result of the rising human population and the increased efficiency of waste disposal systems. Developing nations were found to be experiencing the same eutrophication problems as industrial nations did in the early 1900s.

Description of work: Review. Location: None. Keywords: Eutrophication, Nutrient, Coral

Nixon, S. W., C. A. Oviatt, J. Frithsen and B. Sullivan. 1986. Nutrients and the productivity of estuarine and coastal marine ecosystems. *J. Limnol. Soc. sth. Afr.* **12**: 43-71.

The history of the classic agricultural model of nutrient enrichment and the application of this model to various marine systems was reviewed. Specifically, the results of coastal marine nutrient enrichment experiments were compared with the agricultural model for consistency and accuracy. The authors reviewed data from experiments conducted in European temperate waters, Kaneohe Bay, Narragansett Bay and Scottish lochs. The biggest difference between marine nutrient enrichment models and the agricultural model was that nutrient input to marine systems was taken up very quickly by the primary producers with very little reaching higher trophic levels. Thus the only documented effect that nutrients had on marine systems was to increase the rate of nutrient cycling within the lowest trophic levels.

Description of work: Review. Location: None. Keywords: Eutrophication, Nutrient, Coral

Nordemar, I., M. Nyström and R. Dizon. 2003. Effects of elevated seawater temperature and nitrate enrichment on the branching coral *Porites cylindrical* in the absence of particulate food. *Marine Biology* **142**: 669-677.

The physiological response of the coral *Porites cylindrical* was investigated when exposed to the enrichment of dissolved inorganic nitrate and high water temperature in the absence of food. The coral tolerated temperature increases without losing zooxanthellae or chlorophyll pigment, but photosynthetic ability was affected. Nitrate enrichment reduced primary production rate but did not affect zooxanthellae density and chlorophyll concentrations. Respiration rates were unaffected by the treatments. Observed reductions of tissue growth or biomass suggests a dependence on food. Overall, corals on nutrient-exposed reefs were more stressed during periods of increased temperatures compared to corals unexposed to high nutrient contents.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Temperature, Nutrients, Particulate food, Zooxanthellae, Respiration, Photosynthesis

Paytan, A., G. Shellenbarger, J. Street, M. Gonnee, K. Davis, M. Young and W. Moore. 2006. Submarine groundwater discharge: An important source of new inorganic nitrogen to coral reef ecosystems. *Limnology and Oceanography* **51**: 343-348.

Radium isotope (Ra) activity, measured in disintegrations per minute, was used along with nutrient analysis to determine that submarine groundwater discharge (SGD) supplies nutrients,

especially nitrogen (N) to offshore reefs. Ra and nutrient concentrations were higher in groundwater than in coastal waters by one to two orders of magnitude. The contribution from SGD was highly variable between samples due to the many factors that influence SGD, but there was a general concentration gradient for both nutrients and Ra with concentrations being highest near the shoreline.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Coral, N, Nutrients

Rasheed, M., M. I. Badran, C. Richter and M. Huettel. 2002. Effect of reef framework and bottom sediment on nutrient enrichment in a coral reef of the Gulf of Aqaba, Red Sea. *Marine Ecology Progress Series* **239**: 277-285.

Seasonal changes in nutrient and chlorophyll a concentrations in a fringing reef ecosystem were examined in June and December of 1998 - March 2000. Water samples were collected from coral reef cavities, sediment and free-flowing reef waters at hourly intervals over a period of 24 h in June and December. Nutrient and chlorophyll a concentrations from the coral reef system were analyzed for seasonal changes as well as compared to off shore values. During the summer months the water column at the study site was highly stratified. The temperature drop in winter resulted in well mixed and more homogenous water column with horizontal as well as vertical exchange of nutrients. It was found that nutrient concentrations in the reef waters were slightly higher than offshore water concentrations in the winter. In the summer, however, nutrient concentrations in the reef water were significantly higher than those offshore. Results show that nutrient concentrations in the reef cavity water were 1.2 to 2.3 fold higher than the surrounding water column. Nutrient concentration in the porewater was 15 - 80 times higher than the associated free-stream water. Using Fick's law, the nutrient flux was significantly higher between cavity water and the surrounding reef water than the flux from sediment to reef water. The results of this study highlighted the importance of the reef framework and sediment in trapping particulate organic matter and regenerating nutrients with in the reef ecosystem during the summer months.

Description of work: Field. Location: Red Sea. Keywords: Nutrient, Coral

Rees, J., D. Setiapermana, V. Sharp, J. Weeks and T. Williams. 1999. Evaluation of the impacts of land-based contaminants on the benthic faunas of Jakarta Bay, Indonesia. *Oceanologica ACTA* **22**: 627-640.

Concentrations of Pb, Cu, Zn, Cr, and Ni were measured in seawater, suspended particulate matter (SPM) and sediments, as well as in coral tissues of *Goniopora lobata* and *Lobophyllia hemprichii* along a 72 km transect. Metal concentrations in seawater and SPM showed similar trends throughout the study transect with the highest concentrations being offshore. All metals in the sediments increased from offshore to inshore. The authors suggest that these results indicate a distribution controlled by seasonal hydrodynamics rather than spatial proximity to a pollution source. Very few measurements of metal concentrations in coral tissues were made because of sparse or very poor coral community structure. Those that were sampled showed no significant concentration differences between samples, but trends followed those of metal

concentrations in seawater and SPM. However, coral cover and diversity increased significantly at 2 m sampling depth from inshore to offshore, suggesting that corals near shore are more stressed than those offshore. The authors suggest that the near shore corals were stressed by nutrient or organic pollutants, and not by heavy metals. Metal concentrations in offshore corals reflect seasonal fluctuations in dissolved metal in seawater.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Sediment, Heavy metal, Nutrient

Ryan, J. C. 2001. The Caribbean gets dusted. *Bioscience* **51**: 334-338.

Caribbean corals and residents have long suffered from African dust. Previously, the impact of this dust focused on global impacts of heat and carbon cycles. However, recent research shows the possibility of impacts on the marine ecosystem and public health. This review addresses current evidence which indicates airborne pathogens and nutrients associated with African dust are troubling the marine ecosystems of the Caribbean.

Description of work: Review. Location: None. Keywords: Coral, Dust, Human health, Pathogens, Nutrients

Sakami, T. 2000. Effects of temperature, irradiance, salinity and inorganic nitrogen concentration on coral zooxanthellae in culture. *Fisheries Science* **66**: 1006-1013.

Cultured algae isolated from the hermatypic corals *Pocillopora damicornis* (strain P) and *Montipora verrucosa* (strain M) were tested to define effects of low light intensity, water temperature, salinity and inorganic nutrients. Maximum growth of strain P was observed at 32°C under all light intensities but higher photosystem 2 activity occurred at 28°C. Strain M was more affected by light intensity at all temperatures (24-36°C). Both strains had similar growth rates at low salinity (20-35 PSU) under irradiant light and moderate temperature. Overall, low irradiation and high temperature reduced tolerance against low salinity. Gross photosynthesis per cell was unaffected and cellular chlorophyll a content and cell density increased with ammonium enrichment up to 20 micromoles per day.

Description of work: Laboratory. Location: Japan. Keywords: Coral, Temperature, Salinity, Light intensity, Nutrients, Environmental stress, Zooxanthellae

Shinn, E., R. Reese and C. Reich. 1994. Fate and pathways of injection-well effluent in the Florida Keys. USGS Report 94-276 1-4.

Twenty four wells along the Florida Keys reef tract were sampled over a period of one year to determine changes in salinity, nitrogen, and phosphorus, as well as fecal coliform and fecal streptococcal bacteria. Increased levels of salinity and ammonia were found in offshore groundwater compared to surface waters. Increased levels of nitrogen (as NO<sub>2</sub> and NO<sub>3</sub>) and phosphorus were found in shallow onshore groundwater and, to a lesser extent, in the offshore groundwater. Possible sources of these nutrients were septic tanks and cesspools, as well as agricultural fertilizers. Fecal coliform and fecal streptococcal bacteria were found in three offshore wells located near the Lower Keys, and two shallow onshore wells (Key Largo). The

authors stated that these findings are supporting evidence for offshore transport of water from Key Largo.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Nutrients, Salinity

Shinn, E. A., G. W. Smith, J. M. Prospero, P. Betzer, M. L. Hayes, V. H. Garrison and R. T. Barber. 2000. African dust and the demise of Caribbean coral reefs. *Geophysical Research Letters* **27**: 3029-3032.

It has been proposed that the huge transport of African dust across the Atlantic over the past 25 years has been a contributing factor to the decline of Caribbean coral reefs. Major coral bleaching events and reports of coral mortality coincide with years of maximum dust flux into the Caribbean. The elemental dust is comprised of iron, silicon, and aluminosilicate clays and also is the substrate for spores of soil fungus which has caused seafan disease in the Caribbean. The authors hypothesize that reef degradation is linked to the increase in dust transport and deposition. They propose future changes in the composition of African dust could not only affect coral reef organisms but possibly other ecosystems as well.

Description of work: Review. Location: Caribbean. Keywords: Coral, Dust, Disease, Bleaching, Mortality, Fungus, Nutrients

Sigua, G. C., J. S. Steward and W. A. Tweedale. 2000. Water-quality monitoring and biological integrity assessment in the Indian River Lagoon, Florida: Status, Trends, and Loadings (1988-1994). *Environmental Management* **25**: 199-209.

The Indian River Lagoon (IRL) system extends from Ponce de Leon Inlet to Jupiter Inlet on Florida's east coast. The IRL is subdivided into North and South and is comprised of three interconnected estuarine lagoons. Declines in coverage and species diversity of seagrass communities are believed to be due in part to degradation of water quality. Inflows of phosphorus and nitrogen laden storm water from urban areas and agricultural land have been correlated with higher chlorophyll *a* production. Total Kjeldahl nitrogen was higher in the north than the south section of the IRL while total phosphorus was lowest in the north and highest in the south. Monitoring of the IRL is important to develop water-quality management priorities and plans to direct pollution control toward point and nonpoint sources, and to implement water-quality programs, such as establishing permit limits. This paper describes site-specific differences of water quality and nutrient loading distributions in the IRL system.

Description of work: Field. Location: Indian River Lagoon, Florida. Keywords: Inlet, Phosphorus, Nitrogen, Management, Monitoring, Water quality, Estuary, Seagrass, Nutrient loading

Smith, S. V. and R. W. Buddemeier. 1992. Global change and coral reef ecosystems. *Annual Review of Ecology and Systematics* **23**: 89-118.

This paper reviews known or probable responses of coral reef ecosystems to global change.

Topics discussed include: ecosystem roles and responses; reef responses to environmental variables; pathways of climate forcing; and large-scale, local, scientific, and institutional issues. Description of work: Review. Location: None. Keywords: Coral reef systems, Global change, Carbon dioxide, Sedimentation, Sea level, Temperature, Light, Salinity, Nutrients

Smith, S. V., W. J. Kimmerer, E. A. Laws, R. E. Brock and T. W. Walsh. 1981. Kaneohe Bay sewage diversion experiment: perspectives on ecosystem responses to nutritional perturbation. *Pacific Science* **35**: 279-397.

The effects of sewage inputs to Kaneohe Bay were examined prior to and after the diversion of sewage inputs to an ocean outfall. The variation in nutrient mass balance, before and after sewage diversion, was the main focus of this study. Mass balance calculations provided a general description of circulation in and out of the bay. This data was analyzed to provide an estimate of material flux in the system. Quantitative and qualitative data on water quality and benthic biota were analyzed pre and post sewage diversion. In general, the response of the Kaneohe Bay system to the sewage diversion was very rapid. Many of the parameters decreased to pre-sewage values during the course of this study. Conclusions reached from the study included: 1) N was the limiting nutrient in the bay; 2) nutrient inputs controlled the plankton biomass but not productivity; 3) the metabolism of the benthic community was controlled by particulate loading; 4) a major source of recycled nutrients was the lagoon benthic community.

Description of work: Field. Location: Hawaii. Keywords: Coral, Nutrient

Steven, A., M. Devlin, J. Brodie, M. Baer and M. Lourey (1995). Spatial influence and composition of river plumes in the central Great Barrier Reef. Downstream Effects of Land Use. Rockhampton, Australia, Great Barrier Reef Marine Park Authority: 4.

Swart, P. K., A. Saied and K. Lamb. 2005. Temporal and spatial variation in the  $^{15}\text{N}$  and  $^{13}\text{C}$  of coral tissue and zooxanthellae in *Montastraea faveolata* collected from the Florida reef tract. *Limnology and Oceanography* **50**: 1049-1058.

Temporal and spatial variations (inshore vs. offshore reefs) in  $^{15}\text{N}$  and  $^{13}\text{C}$  concentrations in coral tissue and zooxanthellae were measured. Coral tissue and zooxanthellae samples were taken from five patch reefs off Key Largo, Florida.  $^{13}\text{C}$  values varied seasonally and it was suggested that  $\text{CO}_2$  limitation in the summer months was the cause. No significant intra-annual variation was found in  $^{15}\text{N}$  values except for a general decline over the two year study period. There were no significant differences in the inshore and offshore  $^{15}\text{N}$  and  $^{13}\text{C}$  values.  $^{15}\text{N}$  values above +6 ‰ are accepted as a threshold indicating exposure to sewage. Based on this threshold, the authors concluded that the reefs in this study were not influenced by sewage.

Description of work: Field. Location: Florida. Keywords: Coral, Nutrients

Swarzenski, P., J. Martin and J. Cable. 2001. Submarine ground-water discharge in upper Indian

River Lagoon, Florida. Water Resources Investigations Report 01-4011, USGS 1-10.

Groundwater seepage rates were measured at 28 stations along the north end of the Indian River Lagoon, FL. Lagoon and interstitial water samples were also taken. Seepage rates into the Lagoon were determined using nutrients, chloride (Cl), conductivity, pH, temperature, dissolved oxygen, and various isotope ratios. Seepage rates were found to be 3-100 ml/m<sup>2</sup>/min during the dry season and 22-144 ml/m<sup>2</sup>/min during the rainy season. Seasonal differences may indicate that there is a connection between increased rainfall and increased groundwater seepage. Measurements of Cl indicated that most (95-99%) of the interstitial water was recycled lagoon water and did not originate from groundwater seepage. Nutrient concentrations were found to be 3-5 times higher in the seepage water over the lagoon, indicating that submarine groundwater discharge is important to the coastal nutrient budget.

Description of work: Field. Location: Indian River Lagoon, FL. Keywords: SGD, nutrients, salinity, temperature, pH

Szmant, A. M. 2002. Nutrient enrichment on coral reefs: Is it a major cause of coral reef decline? *Estuaries* **25**: 743-766.

The author reviews the following models concerning phase shifts of coral reefs: the relative dominance model (Littler and Littler 1984); the eutrophic gradient model (Birkeland 1988); and the expanded relative dominance model (Steneck and Dethier 1994). Relationships between coral growth rates, suspended particulate matter, and upwelling were examined. Results from The Enrichment of Nutrients on Coral Reefs Experiment (ENCORE) were specifically analyzed with emphasis on the effects of nutrients on reproductive biology of various species of corals. The author states that none of the field enrichment studies reviewed demonstrated major biological or ecological effects on corals. Various caging/enrichment studies were reviewed and it was concluded that with normal herbivory rates, moderate nutrient enrichment does not result in a change in algal community structure or biomass. A number of studies were cited that showed corals outcompeting macroalgae in elevated nutrient regimes. An overview of nitrification studies around the world was broken down by geographic region, with an emphasis on the lack of conclusive data of direct effects on coral reefs. A few studies have produced ecosystem-wide estimates of coral reef productivity which may be the most accurate method given the size, and spatial complexity of reefs. The author concludes that there is evidence of elevated nutrients directly affecting coral reefs but that these effects are mostly localized events. In light of this, the fate of primary production must be considered in order to fully understand the effects of nitrification on coral reefs. Finally a conceptual model, based on the assumption that higher nutrient fluxes will result in greater gross production rates on coral reefs, is proposed.

Description of work: Review. Location: None. Keywords: Coral, Nutrient

Szmant, A. M. and A. Forrester. 1995. Water column and sediment nitrogen and phosphorus distribution patterns in the Florida Keys, USA. *Coral Reefs* **15**: 21-41.

As a part of the SEAKEYS program, the distribution of N, P and Chl a from near shore to



offshore waters of the Florida reef tract was examined. Five transects were used in the upper keys, two in the middle keys and two in the lower keys. Water and sediment samples were collected over two year period. Sediment N concentrations were generally reduced by half from inshore to offshore, while P increased from inshore to offshore. Two spatial patterns were observed in the combined data for nutrient and Chl a concentrations in the sediment and water column. The first pattern was shown in the upper and lower keys transects. This pattern was characterized by elevated nutrients and chlorophyll concentrations inshore with a drop to oligotrophic levels within 1 km of shore. The second pattern was observed in the middle keys where water column nutrient levels were higher than the upper and lower keys study areas. There was also a much smaller decrease in water and sediment nutrient levels between the inshore and offshore sites. Upwelling may bring as much as 40 times the annual N load and 25 times the P load as compared to the total anthropogenic input to the Florida reef tract. The Florida reef waters studied were below the threshold values of DIN >0.1 uM, PO<sup>4</sup> >.01 uM and Chl a > 0.5 ug/L. Data from this study combined with other recent work suggested that the decline of the Florida coral reefs may be a part of a regional phenomenon associated with global climate change.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral, Sediment, DIN, P, Upwelling

Walker, D. I. and R. F. G. Ormond. 1982. Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin* **13**: 21-25.

The mortality rate of the coral *Stylophora pistillata* at a polluted coral reef site was compared to a control site. The test site was being polluted by primary treated sewage discharge and phosphate dust. 35 coral colonies were monitored in the polluted area. The mortality rate of the coral was found to be 4-5 times higher at the polluted site than at the control site. Glass plates were deployed to measure algal settlement and growth rates at each site. The growth of algae both on the coral and on glass plates was significantly greater at the polluted site. The authors suggest that the increase in algal biomass was only indirectly responsible for coral death and that the increased sediment trapped by the algae on the reef is the actual cause of coral death.

Description of work: Field. Location: Red Sea. Keywords: Eutrophication, Sediment, Coral, Nutrient

Ward-Paige, C. A., M. Risk and O. Sherwood. 2005. Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. *Marine Pollution Bulletin* **In Press**:

This study looked at bioerosion by *Cliona delitrix* and *Cliona lampa* sponges at 43 sites along the Florida Reef Tract during the summer of 2001, and compared these to samples from control sites in Belize. Rose and Risk (1985) positively linked the abundance of *C. delitrix* to concentrations of water column fecal bacteria, and Sammarco (1996) and Holmes et al. (2000) correlated these types of bioeroders with increased nutrient levels. The authors concluded that: coral cover declined as the density of *Clionid* sponges increased from 1996-2001, and this decline was most abundant in the Upper Keys. Nitrogen isotope ratios, sponge size, and sponge cover was also higher in the parts of the Lower Keys where total nitrogen and NH<sub>4</sub><sup>+</sup> were higher

(compared to? The lower nitrogen isotopes values from the Belize sites, signifying alternate nutrient sources. The authors suggest coral decline along the Florida Reef Tract was due to land based pollution sources, not global changes.

Description of work: Field. Location: Florida. Keywords: Coral, Nutrient, Eutrophication, Sewage

Wielgus, J., N. E. Chadwick-Furman and Z. Dubinsky. 2004. Coral cover and partial mortality on anthropogenically impacted coral reefs at Eilat, northern Red Sea. *Marine Pollution Bulletin* **48**: 248-253.

This study examined variations in coral cover and partial mortality at five sites exposed to varying levels of nutrients and inorganic sedimentation at Eilat, northern Red Sea. Photographs were taken to document changes over a 2-year period. Findings showed sites exposed to concentrations of total oxidized nitrogen (TON) between 0.4 and 0.6 micromoles had lower live coral cover and higher mortality than sites exposed to lower TON levels. Overall, levels of TON and the presence of SCUBA divers were significant variables of partial coral mortality while sedimentation rate was not a significant variable.

Description of work: Field. Location: Red Sea. Keywords: Coral, Sedimentation, Nutrients, Mortality, Total oxidized nitrogen

### **Outfalls**

Bloetscher, F. and S. Gokgoz. 2001. Comparison of water quality parameters from South Florida wastewater treatment plants versus potential receiving waters. *Florida Water Resources Journal* 37-45.

This paper discusses the four routes of effluent disposal from wastewater treatment plants in Florida: ocean outfalls, surface discharges, deep well injection, and reuse. Data was obtained from utilities, hydrogeologists, consulting engineers, and files of the Department of Environmental Protection in West Palm Beach and used to summarize averages for: current drinking water standards, open ocean, advanced water treatment, reclaimed water, secondary effluent, ambient waters from the injection zone, lower and upper aquifer zones, aquifer storage and recovery injection zones, and the Biscayne aquifer monitoring zone. This data from the study is presented in table form for the results of inorganic and secondary analysis. The conclusion of the survey was that treatment plants in south Florida are performing well and no adverse health effects from pollutants or nutrients are anticipated.

Description of work: Laboratory. Location: Southeast Florida. Keywords: Outfall, Wastewater treatment, Effluent discharge, Deep well injection, Surface discharge

Bloetscher, F., L. Meday-Futo, W. R. V. Cott and R. Fergan. 2000. City of Hollywood revises industrial pretreatment program. *Water Engineering & Management* **147**: 17-22.

The South Regional (Hollywood) Wastewater Treatment Plant (WWTP) receives secondary

treated wastewater from Davie and Cooper City for disposal as reclaimed water. The WWTP is a 42 MGD plant that utilizes an ocean outfall and reclaimed water for treated effluent disposal. Treated effluent must comply with standards in the Federal NPDES permit, State TOP, and State of Florida Surface Water Discharge Standards, Marine Class III. As part of the permit requirements, the City of Hollywood must sample for lead, copper, cyanide, silver and mercury on a monthly basis. State numerical limits must be met for copper, silver, and mercury. The Florida Department of Environmental Protection (FDEP) requires the city of Hollywood to implement the pretreatment standards set forth in the FAC 62-625. These standards are: to prevent discharges to wastewater facilities that will interfere with its operation, to prevent discharges to facilities that will pass through or otherwise be incompatible, and to improve opportunities to beneficially use domestic wastewater residuals. Each of these requirements were evaluated to determine the future action needed for water treatment. Technicians from the Regulatory Compliance Program physically visited and inspected more than 9,000 business within the WWTP service area. Hollywood's wastewater system was analyzed for more than 220 pollutants, including analyzing the WWTP influent and effluent for all 220 pollutants once a month for 13 consecutive months. Results were as follows; Silver: the City of Hollywood received a Consent Order to improve pretreatment based on WWTP violations of copper and silver levels. Only one of the 13 samples for silver exceeded the State Discharge Standard (SDS) (by 0.5 ppb). All domestic sampling locations were less than 0.5 ppb. Copper: The average WWTP violation for copper was 21.6 ppb. The SDS is 2.9 ppb. The average sample level obtained was 2.8 ppb with three of the 13 samples exceeding the SDS, but no samples exceeded 10 ppb. At industrial locations, an average level of 19 ppb was found while domestic samples ranged from 10-20 ppb. The WWTP removal ratio for copper was 87%, so that effective removal of copper is possible. Lead: 92% of the WWTP effluent lead samples were less than 1 ppb. All lead results in domestic and industrial locations were less than 0.5 ppb. Cyanide: Prior reports of the WWTP state levels over the SDS. Currently, the presence of cyanide in the collection system and in the WWTP influent and effluent was determined to not be a problem. Iron: The average domestic concentration was 1.02 ppm while the SDS is 0.3 ppm. Oil and Grease: The SDS is 5 ppm. The average WWTP influent level during sampling was 19 ppm and the average effluent level was 1.8 ppm. Effluent levels never exceeded the SDS in 13 samples. Overall, there is no indication that industry is a significant contributor of pollutants to the Hollywood WWTP and the WWTP is effective at removing the amount of pollutants it receives. Description of work: Field and Laboratory. Location: Hollywood, Florida. Keywords: Outfall, Hollywood wastewater treatment plant, Effluent, Influent, State Discharge Standard

Broward County Environmental Quality Control Board. 1981. Annual update: Environmental assessment of the north and south regional wastewater outfalls in the Atlantic Ocean at Broward County, Florida. 21 pp.

This annual update discusses two wastewater treatment plants in Broward County: the North Regional Wastewater Treatment Plant, outfall at 2.377 km offshore at 35 m deep; and the South Regional Wastewater Treatment Plant, outfall at 3.05 km offshore at 30 m deep. Discharge capabilities from these plants are 66.0 MGD (million gallons per day) and 40.0 MGD respectively. However, actual discharges measured October 1981 were 34.39 MGD and 32.98 MGD respectively. Both discharge points are visible from the surface on calm days and are located east of the "third reef" community. A study was conducted to determine if the effluent

from these outfalls has had effects on the physical conditions of the surrounding environment through visual diver observation, bivalve collection, and photographic documentation. Six sites were studied for three experimental areas and three "control" areas. Control areas were considered areas not under the direct influence of an outfall discharge. Bivalves were collected and examined for the presence of zinc, cadmium, PCB's and pesticides. Examination the bivalve tissue samples for pesticides and PCB's contained less than the minimum detection limits in all cases. The minimum detection limit for cadmium was 0.25 mg/kg. Seven of the 24 samples were reported as less than the detection limit for cadmium. Statistical analysis showed site 3 (onshore, south side of North Regional Discharge outfall) to have a significantly greater mean zinc value than the other sites. Site 4 (offshore, ~3 miles south of North Regional Discharge outfall) had a significantly higher mean cadmium value than the other sites. Since site 3 is close to the Hillsboro inlet it is presumably under a greater influence from land runoff and tidal exchange and this could be the reason for the zinc content. Overall, one sample from each site resulted in no detection of pesticides of PCB's. Examination of four samples from each of the six sites for zinc and cadmium shoed that bivalves from the shoal area south of the Hillsboro Inlet have significantly higher zinc content and animals from the third reef due west of Commercial Blvd. contained significantly higher amounts of cadmium. The results imply that urban runoff is the probable source of these measured differences.

Description of work: Field and Laboratory. Location: Broward county, Florida. Keywords: Outfall, North and South Regional Wastewater Treatment Plant, Bivalve, Pesticides, PCB, Cadmium, Zinc

Carr, G. B., P. A. Davis, R. E. Fergen and F. Bloetscher. 2000. Water quality impacts of long-term effluent disposal strategies in Southeast Florida. *Water Engineering & Management* **147**: 49-53.

This paper summarizes the objectives and outcomes of the Southeast Florida Ocean Outfall Experiment II (SEFLOE II, 1991-1994). The project was formed to satisfy bio-monitoring concerns and provide information to allow the U.S. EPA to evaluate whether four outfalls in Southeast Florida (Miami-Central, Miami-North, Hollywood, and Broward County) were contributing to environmental degradation. Physical, chemical, and biological data was collected during the project and these data were used to characterize the outfall plumes and current environmental conditions. Findings showed that the outfalls were not contributing to environmental degradation in Southeast Florida.

Description of work: Review. Location: Southeast Florida. Keywords: Outfall, Miami-Central, Miami-North, Hollywood, Broward, SEFLOE II

Christie, D. R. 1997. Characteristics of Southeast Florida Publicly Owned Treatment Works. Southeastern Fisheries Association, Inc. 16 pp.

This report summarizes the characteristics of Southeast Florida's outfalls including: length of the pipe, distance from shore, discharge depth, single port or multiport, permitted discharge capacity, and any plans to expand. Each outfall is also characterized by 1997 effluent water quality criteria including: total nitrogen, total phosphorus, and fecal coliforms. Also included in this report is an excerpt was taken from Looking Seaward: Development of a State Ocean Policy for

Florida. This excerpt discusses pollution control in general, the Clean Water Act, state pollution control, ocean dumping, oil spills and vessel discharge, and marine debris.

Description of work: Review. Location: Southeast Florida. Keywords: Outfall, Effluent, Pollution control, Federal standards, State standards, Clean Water Act

EPA. 2003. Relative Risk Assessment of Management Options for Treated Wastewater in South Florida. United States Environmental Protection Agency 256 pp.

This report is a risk assessment conducted by the EPA investigating four wastewater disposal options: deep-well injection, aquifer recharge, discharge to ocean outfalls, and discharge to surface-water bodies. Risk assessment of these options included identifying and describing risks and potential risks on human and ecological health.

Description of work: Review. Location: Southeast Florida. Keywords: Outfall, Deep-well injection, Aquifer recharge, Surface water discharge, Risk assessment, Human health, Ecological health

Fergen, R. E., P. A. Davis and F. Bloetscher. 2004. Ammonia dynamics on the ocean environment. Florida Water Resources Journal **March**: 33-36.

The Florida Department of Environmental Protection (FDEP) proposed a 0.035 mg/L as the standard for unionized ammonia for open-ocean discharges. This proposal included determining: gaps in ammonia toxicity data, typical ammonia concentrations at the outfall wastewater plants, the point in the plume the standard would be met, exposure time in the plume to get the standard, results of bioassay tests, and any data support from other regulatory agencies for the difference in estuarine and open-ocean conditions. The conclusion of these investigations was that the potential effects of unionized ammonia as a toxic chemical on the ocean surface from treated effluent plumes does not warrant further regulation at this point.

Description of work: Review. Location: Florida outfalls. Keywords: Outfall, Ammonia, Wastewater plant, Plume

Fergen, R. E., P. Vinci and F. Bloetscher. 1999. Water plant membrane reject water in an ocean outfall. Florida Water Resources Journal 24-26.

The Hollywood wastewater treatment plant (WWTP) treats disinfects effluent by chlorination. Up to 51 MGD of chlorinated effluent (42 MGD from the Hollywood WWTP and 9 MGD from Davie/Cooper City) is mixed with reject water from the Hollywood WWTP on a daily basis. The final effluent travels through a 60-inch pipe about two miles into the Atlantic Ocean and discharged at a depth of 93 feet. A permit for a total flow rate of 54 MGD is being considered by the city and the Department of Environmental Protection. This bioassay study for the Hollywood WWTP effluent had the following objectives: collect monitoring data, collect reject water, pre-chlorinated effluent, and combined effluent for potential toxicity, collect concentration data for metals and major ions, collect effluent samples and perform bioassay tests, evaluate bioassay toxicity of each of the water samples using *Mysidopsis bahia* and *Menidia beryllina*, and confirm that 54 MGD is acceptable as a permitted annual outfall capacity. The

bioassay test results were that *M. beryllina* showed no toxicity from the reject water. Although the reject water (100% concentration) was toxic to *M. bahia*, when combined with the WWTP effluent, its impact on the toxicity of the commingled effluent was insignificant. All tests showed that combined effluents were not toxic to either species when salinity was adjusted. The permit of 54 MGD discharge will then be allowed given there are no potential toxicity concerns. The bioassay tests at 30% effluent concentration indicated there was no potential toxicity for the pre-chlorinated WWTP effluent, reject water, dechlorinated combined effluent, chlorinated combined effluent, at the riser, and at the terminus.

Description of work: Field. Location: Hollywood, Florida. Keywords: Outfall, Hollywood wastewater treatment plant, Effluent, Reject water, Combined effluent

Fisher, L. E. 1980. Annual update: Environmental assessment of the Broward County North Regional Outfall. 15 pp.

This annual update was done to determine if the presence of the North Broward (Pompano) outfall and its discharge has had any effect on the physical conditions of the surrounding environment. The Pompano outfall terminus is located 2.377 km offshore just south of the Hillsboro Inlet at a depth of 35 m. The "third reef" is 150 m west of the outfall terminus in 30 m of water and rises to 15 m over a distance of 100 m. Analysis of grain size distribution was done to determine if bottom sediment consistency has remained the unchanged. Sediment analysis was performed to look for the presence of selected trace metals, pesticides, and PCB's attributed to the discharge. Results of the grain size distribution analysis showed no significant difference between the control site and the outfall site. The chemical analysis of bottom sediments showed no pesticides or PCB's above the detection limits. Comparison of chemical analyses of the present study with one performed in 1978-79 shows slight increases for cadmium, chromium, lead, zinc, and nickel with no change or decreases for copper, iron and all chlorinated hydrocarbons. Chromium showed a significant decrease at the terminus of the outfall, lead at the terminus is twice the amount of other sites, and nickel shows a high concentration at the easternmost and deepest site. Overall, no changes have occurred in the consistency of bottom sediments between control and outfall samples. Differences (positive or negative) observed for the trace metals, pesticides, and PCB's may or may not be real; the variability may occur naturally in the sediment. No visual changes in the outfall environment were observed.

Description of work: Field and Laboratory. Location: Pompano, Florida. Keywords: Pompano Outfall, Sediment, Pesticide, PCB, Trace metal, Cadmium, Chromium, Lead, Zinc, Nickel, Copper, Iron

Huang, H., R. E. Fergen, J. J. Tsai and J. R. Proni. 1998. Evaluation of mixing zone models: CORMIX, PLUMES and OMZA with field data from two Florida ocean outfalls. Environmental Hydraulics 249-254.

Data collected from two Florida outfalls (Hollywood and Miami-Central) was evaluated using three mixing zone models: CORMIX, PLUMES, and OMZA. The data was collected during the Southeast Florida Ocean Outfall Experiment II (SEFLOE II) project. Both outfalls discharge secondarily treated domestic sewage. The Hollywood outfall uses a single port outlet while the Miami-Central outfall uses a multiport diffuser. Nearfield dilutions were derived from

measurements of dye and salinity. Other factors that were measured include: effluent discharge rates, ocean currents, and ambient densities. Fourteen data sets were collected at the Hollywood outfall and twenty were collected at the Miami-Central outfall. All three models predicted realistic initial dilution levels for all tests at the Hollywood outfall. For the Miami-Central data out of 20 predictions, three cases in the CORMIX model and two cases in the PLUMES model were unrealistic when compared to the data. For both nearfield and farfield tests, CORMIX overestimated dye concentrations for the tests at the Hollywood outfall and underestimated concentrations within the 300-400 m range for tests at the Miami-Central outfall. The PLUMES model fit well with the field data from 300-800 m but did not fit well within the 300 m range at both outfalls. The OMZA model fit well with the field data within 800 m for tests at both outfalls.

Description of work: Field. Location: Hollywood and Miami-Central. Keywords: Outfall, Hollywood, Miami-Central, Models, Tracers, Hydrodynamics, Dilution, Effluent

Huang, H., J. R. Proni and J. J. Tsai. 1994. Probabilistic approach to initial dilution of ocean outfalls. *Water Environment Research* **66**: 787-793.

This paper presents a probabilistic approach for the initial dilution of ocean outfall discharges in South Florida. The probabilistic approach is compared with a currently used approach called the worst case approach, first recommended by Tetra Tech. The worst case is defined as the combination of parameters which affect the initial dilution each taken at the worst 10th percentile on cumulative frequency distributions. The 10th percentile values are inputted into a dilution model to give a single value called the worst case dilution. The water quality standard is then set so that the worst case dilution must be greater than that specified value. The state of Florida sets a value of 20 for the flux-averaged initial dilution and this criteria is applied to secondary-treated effluent discharges from outfalls in Southeast Florida. The worst case approach fails to estimate the probability that the worst case dilution occurs at a given outfall and the exposure risk for the marine environment is unknown. The probabilistic approach presented provides a framework for combining available data resulting in a description of initial dilution as a function of cumulative probability from which standards can be defined and the exposure risk level for the marine environment can be estimated. A case study of the Miami-Central outfall is used to compare the worst case approach and the probabilistic approach.

Description of work: Laboratory. Location: Florida. Keywords: Outfall, Miami-Central, Dilution, Effluent, Model, Worst case approach

Iversen, E. S. and E. F. Corcoran. 1976. Broward county off-shore environmental study. Rosenstiel School of Marine and Atmospheric Science, University of Miami 143 pp.

The objective of this study was to investigate whether secondary treated effluent released by the outfalls was degrading the environment and whether this treatment should be upgraded to the level of advanced waste water treatment. Findings showed that the presence of other sources of pollution (i.e. coastal runoff, fuel from vessels, boats without sewage holding tanks) around the outfalls made it difficult to measure the sole effect of the effluent. Improvements in the current methods could be made to remedy this problem. Overall conclusions were that some environmental degradation is present, however the ecology of the area is healthy. Evidence

shows that high levels of chemical pollutants in the water column are not the result of outfall effluent. Secondary treatment of sewage is adequate even at high levels of effluent flow and reduced current. However, environmental damage may result if the level of effluent flow is increased dramatically and the current flow is also greatly reduced at the same time.

Description of work: Field. Location: Broward County. Keywords: Outfall, Effluent, Secondary Treated, Environmental degradation, Pollution, Current, Flow

Michel, J. F. 1972. Oceanographic studies pertaining to the proposed ocean outfall at Pompano Beach, Florida. Ross, Saarinen, Bolton and Wilder, Inc. 18 pp.

This project was conducted by the Engineering firm of Ross, Saarinen, Bolton and Wilder Inc. retained by the Broward County Utilities Department to design a sewer system in Pompano Beach. The system will have a capacity of 20 million gallons per day and a high level of effluent treatment. The Rosenstiel School of Marine and Atmospheric Science at the University of Miami was retained to investigate the oceanographic parameters that should be considered during the design process of the outfall. This report discusses the steps taken to locate the most feasible site for the outfall, the best routing at that site, and develop design criteria. Offshore circulation data in the Pompano area was collected during a three-year study by the Florida Ocean Sciences Institute. These data explain the offshore circulation is dominated by the Florida Current and that wind and tide have little effect. The flow is towards the north, but instabilities along the shore cause eddies to form and reverse the direction of the current. Currents flow north 62% of the time with a mean velocity of .45 knots. Currents flow south 31% of the time with a mean velocity of .39 knots. Onshore currents combined with winds may pose a problem by allowing the effluent to reach the beach in high concentrations. However, the near-shore eddies promote mixing and diffusion of the effluent. The high degree of treatment proposed should eliminate the problem of floating solids as long as the outfall is a good distance from shore. Description of work: Proposal. Location: Pompano, Florida. Keywords: Pompano Outfall proposal, Florida Current, Mixing, Diffusion

Parnell, B. D. 1979. Environmental impact assessment of North Broward (Pompano) outfall. Environmental Quality Control Board 14 pp.

Following submission of the Iverson and Corcoran report of 1976, recommendations were made by the Water Pollution Committee of the Broward County Environmental Quality Control Board for continuing studies and formation of a program to monitor the North Broward County (Pompano) Outfall for at least one year. The objectives of this assessment were: to develop a program for studies to compare to the baseline study, photos of benthic habitats, analysis of bottom sediments, and measurement of current flow. Further objectives were added and included: identifying benthic macrofauna, determination of biological health status, geological studies of reefs at the outfall, and photos of study sites. This paper is an interim report of this study.

Description of work: Field. Location: Pompano Outfall. Keywords: Outfall, Environmental conditions, Effluent, Benthic habitat, Sediment analysis



Proni, J. R. and P. Dammann. 1989. Southeast Florida Outfall Experiments (SEFLOE).  
Technical Report 58 pp.

This original SEFLOE experiment was performed to investigate the mixing, dispersion, and dilution of the wastewater effluent plumes discharged at open ocean outfalls along the coast of Southeast Florida. Each of the six south Florida wastewater outfalls (Miami-Central, Delray, Broward, Boca Raton, Hollywood, and Miami-North) were tested. This experiment resulted in new knowledge of sampling techniques, instrument performance in the field, and monitoring data for the outfalls was obtained.

Description of work: Field. Location: Southeast Florida. Keywords: Outfall, Miami-Central, Miami-North, Broward, Delray, Boca Raton, Hollywood, Effluent, Plume

Proni, J. R., H. Huang and W. P. Dammann. 1994. Initial dilution of Southeast Florida ocean outfalls. *Journal of Hydraulic Engineering* **120**: 1409-1425.

Initial dilutions (the minimum surface or near-surface dilution) were determined using dye and salinity studies at four Florida outfalls: the Miami-Central, Miami-North, Hollywood and Broward. The Hollywood and Broward outfalls use single-port discharges while the Miami-Central and Miami-North outfalls use multiport diffuser discharges. For the dye test, the red dye Rhodamine-WT was injected into the effluent and measured using a fluorometer. The salinity studies were conducted by measuring temperature and conductivity. The results indicated both methods were consistent. Comparisons were made with previously collected data of the outfalls. Data from the Hollywood and Broward outfalls were consistent with previous data (single-port discharges) while the two Miami outfalls (multiport diffuser discharges) were not consistent with data for single-port discharges.

Description of work: Field. Location: Miami-Central, Miami-North, Hollywood, and Broward. Keywords: Outfall, Miami-Central, Miami-North, Hollywood, Broward, Tracers, Hydrodynamics, Dilution, Effluent

Broward County Department of Planning and Environmental Protection. 2001. Broward County, Florida Historical Water Quality Atlas: 1972-1997. Technical Report **TR: 01-03**: 415 pp.

Since 1972 the Broward County Department of Planning and Environmental Protection (BCDPEP) has monitored the water quality of Broward County's waterways. The goal of the BCDPEP since 1988 has been to understand ambient water quality conditions throughout the urban portions of the county as part of the habitat realm of biological populations they may sustain. This atlas provides a comprehensive update on the county's ambient water quality and depicts historical characteristics from 1972-1997.

Description of work: Technical Report. Location: Broward County. Keywords: Water quality, Broward county, Surface waters, Inlets, Outfalls

### **Pharmaceuticals/Organics**

Atkinson, S., M. Atkinson and A. Tarrant. 2003. Estrogens from sewage in coastal marine environments. *Environmental Health Perspectives* **111**: 1-7.

Estrogen concentrations were measured in sewage, at injection wells, coastal and offshore tropical waters at 20 sites. Estrogen was undetectable (<40pg/L) in the open ocean but increased to approximately 2,000 pg/L around Key West, Florida and Rehoboth Bay, Delaware. Less than 20% of estrogen per week was deposited into sediments indicating that estrogens would tend to leach from septic fields and groundwater into the surrounding marine environment. Mean estrogen concentration at 12 sites were above 300 pg/L, the concentration at which corals begin to take up estrogens from the water column. The authors stated that the impacts of estrogens on corals are unknown.

Description of work: Field and Laboratory. Location: Caribbean, Florida, Hawaii. Keywords: Pharmaceutical, Estrogen, Sewage, Coral

Cheevaporn, V. and P. Menasveta. 2003. Water pollution and habitat degradation in the Gulf of Thailand. *Marine Pollution Bulletin* **47**: 43-51.

Several pollution sources were examined with respect to their effects on fisheries, aqua culture, coral and mangrove resources, and oil and mineral resources in the Gulf of Thailand. The authors classified the pollution sources into four categories; untreated municipal and industrial wastewater, excess nutrients, trace metals contamination, and petroleum hydrocarbon contamination. Rapid population growth, followed by industrialization has depleted resources and led to a worsening in environmental quality. Untreated wastewater is listed as the principle problem affecting the area, followed by eutrophication. The authors found little evidence of petroleum hydrocarbon contamination from oil spills, but fears still exist that there may be a large scale spill in the future. Also, trace metal contamination seemed to be minimal. Although Thailand has implemented a program for marine pollution control including baseline monitoring studies, water quality standards, identification of pollution sources, pathways, and quantities, as well as some pollution control and rehabilitation efforts; many of these areas are still under-emphasized.

Description of work: Review. Location: Asia. Keywords: HAB, Nutrients, Coral, Thailand, Sewage, Organic

Dodge, R., A. Knap, S. Wyers, H. Frith, T. Sleeter and S. Smith. 1985. The effect of dispersed oil on the calcification rate of the reef-building coral *Diploria strigosa*. *Proceedings of the 5<sup>th</sup> International Coral Reef Congress* **6**: 453-457.

This experiment simulated a short term oil spill treated with a dispersant passing over a coral reef, by exposing colonies of *Diploria strigosa* to chemically dispersed oil treatments at concentrations of 20 ppm for a 24 hour period. Changes in calcification rates were observed following the treatments. The authors suggest that changes in calcification rates can be used as a possible indicator of sub-lethal effects of chemically dispersed oil. There was no decrease in calcification rates observed up to 30 days following the treatments. However, prominent short-term stress symptoms were observed.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Chemical dispersants,

## Oil, Organic

Dodge, R. E., S. C. Wyers, H. R. Frith, A. H. Knap, S. R. Smith and T. D. Sleeter. 1984. The effects of oil and oil dispersants on the skeletal growth of the hermatypic coral *Diploria strigosa*. *Coral Reefs* **3**: 191-198.

Long-term effects of brief exposure to low-level concentrations of chemically dispersed oil on corals *Diploria strigosa* were studied. Septa increase, columella increase, fossa length and new endotheca length were analyzed. Only fossa length was significantly affected by the experimental treatment, and then only in two experiments. The fossa length in these two cases was depressed in some of the corals. The authors stated that given the unprecise answers to the effects of short and long term dispersed oil pollution, more experiments would be useful.

Description of work: Laboratory and Field. Location: Caribbean. Keywords: Coral, Chemical dispersants, Oil, Extension growth, Organic

Fabricius, K. and M. Dommissie. 2000. Depletion of suspended particulate matter over coastal reef communities dominated by zooxanthellate soft corals. *Marine Ecology Progress Series* **196**: 157-167.

The authors investigated the *in situ* rates of net depletion of natural suspended particulate matter (SPM) by reefs dominated by zooxanthellate alcyoniid soft corals. Concentrations of SPM in water parcels were measured before and after passing over 2 soft coral dominated reef strips and 2 sand-dominated strips. Downstream of the reef there was a depletion of chlorophyll, particulate organic carbon, and particulate phosphorus. The standing stock averaged 35% chlorophyll depletion while net depletion for particulate organic carbon and particulate phosphorus were 15 and 23% respectively. Concentrations of particulate nitrogen and phaeopigments were similar before and after passage across the reef sites. On the sandy sites, downstream concentrations of particulate nitrogen, chlorophyll, and phaeopigments were similar to upstream concentrations. The net import of particulate organic carbon into the reef was estimated to be  $\sim 2.5 \text{ g C/m}^2/\text{d}$ . Less than 20% of this import could be explained by removal sponges, tunicates, bivalves, and hard corals, suggesting that soft corals were the primary sinks of carbon. Overall, it is suggested that detritus and other small SPM are an important food sources for alcyoniid-dominated reef communities that experience high levels of turbidity.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral reef community, Turbidity, Suspended particulate matter (SPM), Particulate organic matter (POM), Suspension feeding

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient

loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Isidori, M., M. Lavorgna, A. Nardelli, A. Parrella, L. Previtera and M. Rubino. 2005. Ecotoxicity of naproxen and its phototransformation products. *Science of the Total Environment* 1-9.

The toxic effects of naproxen and its phototransformation products were tested in algae, rotifers and microcrustaceans. It was found that the phototransformation products of naproxen were significantly more toxic to all three organisms tested compared to the parent compound. Chronic exposure to all compounds caused more toxicity than acute exposure. The toxic values for naproxen were on the order of mg/l, while concentrations found in waters have been reported to range from 0.02-0.52 ug/l. Chronic toxicity was observed for some of the photoproducts in concentrations of ug/l. This indicates the need for further study on the effects of long term exposure to low dose concentrations of naproxen and other drugs, as well as their transformation products.

Description of work: Review. Location: none. Keywords: Pharmaceutical

Kuntz, N. M., D. I. Kline, S. A. Sandin and F. Rohwer. 2005. Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species. *Marine Ecology Progress Series* **294**: 173-180.

In this study, *Montastraea annularis*, *Agaricia tenuifolia*, and *Porites furcata* were exposed to various carbon sources (starch, lactose, arabinose, and mannose) and nutrients (combinations of phosphate, ammonium and nitrate) in order to record different species-specific and carbon-specific pathologies and rates of mortality. Results showed that the three species displayed different pathologies and mortality rates to treatments. This variation in pathological characteristics to stressors showed that visual cues for determining coral health may be misleading. Mortality increased over time with continual exposure to several stressors suggesting that chronic stress may be more harmful than acute. Unlike organic carbon sources, high concentrations of nutrients did not directly kill corals. Overall, the observed variations in coral responses to stressors means that changes on disturbed coral reefs will depend on the type and duration of exposure to the stressor as well as the coral species.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Disease, Stress,

Nutrients, Organic carbon, Anthropogenic stress

Marubini, F. and B. Thake. 1999. Bicarbonate addition promotes coral growth. *Limnology and Oceanography* **44**: 716-720.

This study tested if the supply of dissolved inorganic carbon (DIC) in seawater limits calcification. Nubbins of the hermatypic coral *Porites porites* cultured in seawater were compared to nubbins of the same coral cultured in DIC-enriched (+2 mM) seawater. The authors also tested if limitation of calcification by nitrogen can be compensated for by DIC enrichment. In the case of the DIC-enriched seawater, skeletal growth rate of the coral doubled. Nitrate or ammonium addition (20 micromoles) caused a significant reduction in coral growth. However, when seawater with the extra bicarbonate was supplemented with nitrogen, no growth depression occurred. Overall, the dissolved inorganic carbon content of the ocean limited coral growth, this limitation was exacerbated by the presence of nitrate and ammonium, and adding DIC increased coral calcification rates and protected against nutrient enrichment.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral growth, Calcification, Dissolved inorganic carbon, Nutrient enrichment

Peters, E. C., N. J. Gassman, J. C. Fireman, R. H. Richmond and E. A. Power. 1997. Eco toxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* **16**: 12-40.

Information gaps related to the effects of chemical contaminants on tropical marine ecosystems were evaluated. Heavy metals, petroleum, and synthetic organics were discussed in the context of ecosystem management and ecological risk assessment. Some of the most important sources of pollutants are terrestrial runoff, sewage outfalls, desalination plants, landfills, oil refineries and tanker spills. Coral colonies can be affected by all of these. Exposure to heavy metals causes production of mucus and expulsion of symbiotes as a means of excretion, reduced growth rate and species diversity also occur in reefs exposed to metals. Research suggests that small scale chronic oil spills may be more toxic than single large scale spills. Dispersants in combination with oil also increased tissue death and bleaching events in corals. Studies show increasing levels of pesticides, particularly lindane, DDT, and chlordane in nearly 100% of corals in the Great Barrier Reef and reefs off the Florida Keys. In general, data on pollutants and biological responses is much more complete for temperate marine and freshwater systems. It has not yet been established if the fate and transport of pollutants in tropical marine systems is similar to that of temperate systems. Most monitoring programs in tropical systems quantified ecological responses but provided limited data on the stressors. Data on toxic pollutant levels that caused adverse effects in the field are limited. The author suggests that studies need to be done where contaminant levels in the water, sediment, and organisms are all measured at the same time in the same locations, and that researchers need to use the latest technology and appropriate identification protocols to produce more accurate results.

Description of work: Review. Location: None. Keywords: Coral, Heavy metal, Pharmaceutical, Organic, Pesticide, Herbicide

Peters, E. C., P. Meuers, P. Yevich and N. Blake. 1981. Bioaccumulation and histopathological effects of oil on a stony coral. *Marine Pollution Bulletin* **12**: 333-339.

*Manicina areolata* colonies were exposed to No. 2 fuel oil for three months. These colonies incorporated petroleum hydrocarbons into their tissues during this time. The authors found impaired development to reproductive tissues, damage to and/or loss of zooxanthellae, and damage to mucous cells. All of these colonies still showed signs of hydrocarbon contamination even after being placed in clean seawater for 2 weeks. The authors state "chronic exposures to oil hydrocarbons, even in low concentrations, begin a process of cellular degeneration and atrophy of the coral tissue as well as reducing the ability of the coral to reproduce."

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Oil, Organic

Tarrant, A., M. Atkinson and S. Atkinson. 2004. Effects of steroidal estrogens on coral growth and reproduction. *Marine Ecology Progress Series* **269**: 121-129.

Three experiments were conducted to determine the effects of estrogen on coral growth and reproduction. Exposure to estradiol caused a reduction in the number of egg-sperm bundles released by *Montipora capitata* colonies by 29% compared to a control. In two growth experiments, fall and spring, colonies of *Porites compressa* exposed to estrone grew 24% and 13% slower than controls respectively. Also, in the spring growth experiment tissue was significantly thicker in the treated colonies. The authors suggest that estrogens are biologically active in corals and that exposure to estrogens can cause tissue thickening at the expense of skeletal growth and reduced fecundity in corals.

Description of work: Field and Laboratory. Location: Hawaii. Keywords: Coral, Pharmaceutical, Estrogen

Wu, R. 1999. Eutrophication, water borne pathogens and xenobiotic compounds: Environmental risks and challenges. *Marine Pollution Bulletin* **39**: 1-12, 11-22.

Eutrophication is increasing with increasing human population, especially near coastal areas. This has led to changes in structure and function of phytoplankton, zooplankton, benthic and fish communities. Eutrophication also leads to harmful algal blooms (HABs) which have detrimental effects to coral reefs and human health. Water borne pathogens, mainly from sewage, can also cause human illness and coral reef decline. Current monitoring techniques are inadequate. The author suggests that molecular techniques, like gene probes and multiplex polymerase chain reaction (PCR), may be used in the future to better detect the presence of pathogens in the water column. Xenobiotics have been shown to cause reproductive failure in a number of marine organisms; however the mechanisms of toxicity of these compounds are not well understood. Since these compounds are generally found in low concentrations, the author suggests future research focus on exposing many different species of marine organisms to varying low concentrations. The author also suggests studying the synergistic effects of xenobiotic compounds along with other pollutants.

Description of work: Review. Location: none. Keywords: Pharmaceutical, Organic

Wyers, S. C., H. Frith, R. Dodge, S. Smith, A. Knap and T. Sleeter. 1986. Behavioural effects of chemically dispersed oil and subsequent recovery in *Diploria strigosa* (DANA). *Marine Ecology* **7**: 23-42.

The experiment simulated a major short-term oil spill in shallow subtidal benthic reef environment by exposing *Diploria strigosa* to doses of water-accommodated fractions of chemically dispersed crude oil for 6-24 hours. The findings of this study were similar to prior studies in which corals have been exposed to oil/seawater preparations. Among those findings were altered behavior, extensive pigment loss, extreme tissue contraction and localized rupture. These effects were generally found in only the highest concentration fractions at 24 hour exposure and varied between colonies. All colonies typically recovered in 2 hours to 4 days after being transferred to clean seawater. The authors suggest that this recovery indicates an unlikely of long-term impairment.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Oil, Organic

Yamada, K., Y. Suzuki, B. E. Casareto and H. Komiyama. 2003. Possibility of high CO<sub>2</sub> fixation rate by coral reef ecosystems. In: Gale, J. and Y. Kaya (eds): Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies **Pergamon**: 817-822.

This paper reports on the effect of increased flow of seawater over coral reefs and estimates potential increases in CO<sub>2</sub> fixation rates world wide. Previous estimates of net rates of CO<sub>2</sub> fixation by reef ecosystems were said to be nearly zero due to a balance between CO<sub>2</sub> fixed by organic carbon production and CO<sub>2</sub> released by organic carbon decomposition and inorganic carbon formation. This study showed net rates of about 7 gC/m<sup>2</sup>/d over coral reefs. This study found photosynthetic rates of corals increased with the increased flow of seawater. The flow rate over the coral reef on the open-sea side was found to be much higher than in a lagoon. The CO<sub>2</sub> fixation rates at the flow rates of 6 and 30 cm/s were compared. At the flow rate of 30 cm/s the CO<sub>2</sub> fixation rate was 3.5 gC/m<sup>2</sup>/d. This value is 2.2 times higher than at the flow rate of 6 cm/s. This fixation rate is only by coral itself. A global estimate of the CO<sub>2</sub> fixation rate could be on the order of 10,000,000-100,000,000 t-C/y.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral reef, Carbon Dioxide fixation rate, Photosynthetic rates, Flow rate, Organic carbon, Inorganic carbon

### **Salinity**

Alutain, S., J. Boberg, M. Nyström and M. Tedengren. 2001. Effects of the multiple stressors copper and reduced salinity on the metabolism of the hermatypic coral *Porites lutea*. *Marine Environmental Research* **52**: 289-299.

The physiological effects on the hermatypic coral *Porites lutea* was studied when exposed to a combination of reduced salinity (30 psu-20 psu ambient) and two concentrations of copper (10 micrograms and 30 micrograms). The physiological response was estimated by measuring net primary production rate and respiration per surface area. There were no significant effects on respiration rate in any of the treatments when compared to controls or between each other. Exposure to 30 micrograms of copper and reduced salinity significantly reduced production rate

and chlorophyll *a* concentrations while corals exposed to 10 micrograms of copper remained unaffected.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Coral, Copper, Salinity, Disturbance, Metabolism, Multiple stress pollution

Coles, S. L. and P. L. Jokiel. 1978. Synergistic effects of temperature, salinity and light on the hermatypic coral *Montipora verrucosa*. *Marine Biology* **49**: 187-195.

Temperature tolerance of the hermatypic coral *Montipora verrucosa* was investigated. Findings showed the coral was affected by changes in salinity and light. Low salinity reduced its ability to survive short-term exposure to high temperatures (32-33°C). High natural light intensity worsened damage at a high temperatures. High light intensity caused loss of zooxanthellae pigment, increased mortality, reduced carbon fixation and decreased growth rate at both upper (increase of 4-5°C) and lower temperature limits in the long-term. Synergistic effects between parameters as well as the direct effect of each individual variable were important in determining environmental tolerance of the coral species.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Temperature, Salinity, Light intensity, Zooxanthellae, Mortality, Carbon fixation, Sublethal temperature

Costa Jr., O. S., Z. M. A. N. Leao, M. Nimmo and M. J. Attrill. 2000. Nutrifcation impacts on coral reefs from northern Bahia, Brazil. *Hydrobiologia* **440**: 307-315.

The contamination of groundwater and its pathway to coastal waters and fringing coral reefs of the east central coast of Brazil was examined. The study area included two transects from coastal lakes, across two sand barriers to the coral reefs. One transect was located in an urbanized area characterized with septic systems for waste disposal. The other transect crossed a geologically similar but uninhabited area. Pollution levels at the two sites were determined by analysis of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NO}_4^+$ ,  $\text{PO}_4$  and silicate. pH, salinity, temperature and fecal coliform concentrations were used as ground water tracers. Samples were taken in the dry and rainy seasons of 1997. Ecological assessment of the reef system was also conducted and quantified using data from 130 sites. All parameters were higher in the reef waters adjacent to the urbanized area. pH and fecal coliform values indicated human waste contamination of the ground water at the urbanized site. Silicate and salinity values suggested that eutrophication of coastal waters was occurring at the urbanized location. The reefs at the urbanized locations were found to be much more degraded than those adjacent to the uninhabited sites.

Description of work: Field. Location: South America. Keywords: Coral, Eutrophication, Sewage, SGD, Nutrient, Salinity, Temperature, pH, Fecal Coliform

Ferrier-Pagès, C., J.-P. Gattuso and J. Jaubert. 1999. Effect of small variations in salinity on the rates of photosynthesis and respiration of the zooxanthellate coral *Stylophora pistillata*. *Marine Ecology Progress Series* **181**: 309-314.

A 3-week study was performed to determine the effect of small variations in salinity (increase or



decrease of 2-4 psu) on the photosynthesis and respiration of the Red Sea coral *Stylophora pistillata*. Colonies were exposed to four levels of salinity: 34, 36, 38, and 40 psu with 38 psu as the control. Protein concentration was 30% higher at the salinity of 38 psu than all other salinities. Gross maximum photosynthetic rates were 50% lower at 34, 36, and 40 psu than at 38 psu. The P:R ratio was higher at the control salinity in all instances. Most colonies at 40 psu died, with a low P:R ratio of <1. Overall, *S. pistillata* was sensitive to small changes in salinity and acclimated more easily to hypo- rather than hyper- saline conditions.

Description of work: Laboratory. Location: Red Sea. Keywords: Coral, Salinity, Photosynthesis, Respiration

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Hoegh-Guldberg, O. and G. J. Smith. 1989. The effect of sudden changes in temperature, light and salinity on the population density and export of zooxanthellae from the reef corals *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana. *Journal of Experimental Marine Biology and Ecology* **129**: 279-303.

This study investigated the bleaching of two pocilloporid corals, *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana, in the northern Great Barrier Reef. Both naturally and experimentally bleached corals were used to answer these questions: (1) Is color loss due to the loss of zooxanthellae or reduced amount of photosynthetic pigment? (2) Are there different characteristics of bleaching due to light exposure as opposed to elevated temperature or reduced salinity? (3) Does the rate of zooxanthellae expulsion increase when corals are exposed to conditions that cause bleaching? Naturally bleached colonies had the same amount of chlorophyll *a* in the zooxanthellae but had reduced population densities of zooxanthellae when compared to normal colonies. In this case, bleaching was explained by low numbers of

zooxanthellae and not by pale zooxanthellae. In laboratory corals, sudden exposure to full sunlight induced the bleaching of *S. pistillata*. The pale color of colonies was explained by the low pigment content of the zooxanthellae rather than low population densities. Sudden exposure to reduced salinities (30 ppt) did not affect either coral species. However, both species bleached rapidly when exposed to water temperatures above 30°C. Zooxanthellae expulsion rates remained high, even after corals were returned to control temperatures (27°C). In this case, bleached corals had reduced population densities despite normal pigment contents. Recovery of corals after temperature shock was also investigated.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Bleaching, Irradiance, Light, Stress, Temperature, Zooxanthellae, Salinity

Jokiel, P. I., C. L. Hunter, S. Taguchi and L. Watarai. 1993. Ecological impact of a fresh-water "reef kill" in Kaneohe Bay, Oahu, Hawaii. *Coral Reefs* **12**: 177-184.

Storm floods on December 31, 1987 reduced surface water salinity to 15 ppt in Kaneohe Bay, Hawaii. This flood resulted in mass mortality of coral reef organisms including corals, echinoderms, crustaceans, and others. Virtually all coral was killed to depths of 1-2 meters following which the coral *Porites compressa* dominated the area. Similar floods occur every 20 to 50 years in the area. The last major fresh water reef kill was in 1965 when sewage was being discharged into the bay. This paper compares recovery of reefs under non-polluted and polluted conditions. Findings showed coral reefs are able to recover relatively quick from natural disturbances, but not under polluted conditions.

Description of work: Field. Location: Hawaii. Keywords: Coral, Flood, Mortality, Pollution, Reef kill, Salinity

Kuta, K. G. and L. L. Richardson. 2002. Ecological aspects of black band disease of corals: relationships between disease incidence and environmental factors. *Coral Reefs* **21**: 393-398.

Salinity, water depth, water temperature, nitrate, nitrite, ammonium, soluble phosphate, total phosphate, turbidity, coral diversity, and percent coral cover were measured at 190 sites on 12 patch reefs. Twenty-one of the sites contained a colony with active black band disease and 169 sites contained healthy colonies susceptible to the disease. Water temperature, depth, coral diversity, and concentrations of orthophosphate and nitrite showed statistically significant relationships with the disease.

Description of work: Field. Location: Florida. Keywords: Black band disease, Coral reef ecology, Coral reef health, Salinity, Temperature, Nutrients

Lirman, D., B. Orlando, S. Maciá, D. Manzello, L. Kaufman, P. Biber and T. Jones. 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: Diversity, abundance, distribution, and environmental correlates. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**: 121-135.

The hardbottom habitat of Biscayne Bay make it a marginal environment for coral growth. An

assessment of the Bay was performed to evaluate the coral populations present and investigate the factors that limit coral abundance, diversity, and distribution. Considering future changes in freshwater delivery into Biscayne Bay, due to the Everglades restoration, would affect salinity patterns and increase sediment loads which in turn are important to the abundance and distribution of corals in the area. Biscayne Bay contains a limited number of coral species. The physical characteristics of the basin make it a marginal environment for coral growth so the presence of *Siderastrea radians* and *Porites furcata* in Biscayne Bay indicate that these species are able to tolerate fluctuating conditions. Three factors, temperature, sedimentation, and salinity appeared to limit coral abundance, diversity and distribution in the bay. Sediment burial was shown experimentally to influence growth and mortality of *S. radians*. The salinity of the bay is influenced by freshwater inputs from canal, sheetflow, and groundwater sources that create a low mean salinity near-shore environment with large salinity fluctuation. Chronic exposure to low salinity was shown experimentally to decrease the growth of *S. radians*. The location of Biscayne Bay, downstream of the Everglades watershed, highlights the need to understand the relationship between the physical environment and the benthic community health.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral community, South Florida, Salinity, Sedimentation, Temperature, Hardbottom habitat, Everglades restoration

Manzello, D. and D. Lirman. 2003. The photosynthetic resilience of *Porites furcata* to salinity disturbance. *Coral Reefs* **22**: 537-540.

*Porites furcata* is one of the most abundant coral species in the shallow lagoon of Biscayne Bay, Florida. Variable salinity, temperature and high sedimentation make it a marginal environment for coral growth. *P. furcata* was tested to investigate its tolerance for salinity fluctuations to occupy this environment. This species had the capacity to survive sudden salinity changes without tissue mortality, maintained autotrophy during salinity stress, acclimated to short-term salinity changes, and rapidly recovered photosynthetic rates after a return to ambient salinity. Overall, *P. furcata* survived in a marginal reef environment.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Salinity, Photosynthetic response, Temperature, Sedimentation, Coral stress

Moberg, F., M. Nyström, N. Kautsky, M. Tedengren and P. Jarayabhand. 1997. Effects of reduced salinity on the rates of photosynthesis and respiration in the hermatypic corals *Porites lutea* and *Pocillopora damicornis*. *Marine Ecology Progress Series* **157**: 53-59.

This study investigated the effects of changes in salinity on *Porites lutea* and *Pocillopora damicornis* in the Inner Gulf of Thailand. The authors hypothesized that heterotrophic feeding will be more important in areas like the inner Gulf of Thailand, where photosynthesis might be reduced from turbidity and salinity stress. Photosynthetic and respiratory rates were measured as changes in dissolved oxygen levels per hour and the gross production to respiration ratio ( $Pg:R$ ) was calculated.  $Pg:R$  ratios were significantly lowered in both species when exposed to sudden salinity drops (30 ppt to 20 ppt and 10 ppt) with *P. lutea* being slightly less affected. Photosynthetic rates were lowered in proportion to the salinity change in both species, whereas respiration rates were decreased or unchanged.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Salinity,

## Photosynthesis, Respiration

Muthiga, N. A. and A. M. Szmant. 1987. The effects of salinity stress on the rates of aerobic respiration and photosynthesis in the hermatypic coral *Siderastrea siderea*. *Biological Bulletin* **173**: 539-551.

*Siderastrea siderea* was subjected to long-term and sudden decreases and increases in salinity. Measurements of oxygen concentration were taken to determine rates of aerobic respiration and photosynthesis during the experimental trials. When salinity was increased slowly over a 30 day period, the coral was able to acclimate to an increase from ~30 - 42 ppt. Respiratory and photosynthetic rates were not inhibited by salinity changes of less than 10 ppt above or below 42 ppt. Sudden increases or decreases in salinity of greater magnitude negatively affected respiratory and photosynthetic rates proportional to the magnitude of the salinity change. Overall, *S. siderea* was able to long and short term changes in salinity.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Salinity, Oxygen concentration, Photosynthetic rate, Aerobic respiration

Pitts, P. A. 2001. Hyperpycnal plumes in shelf waters of the Exuma Cays, Bahamas: A trigger for coral bleaching? *Cold Water Diving for Science* 95-100.

Increased solar radiation and high evaporation during the summer causes the waters of the Great Bahama Bank to increase in temperature and salinity. During tidal fluctuations, this water is pushed through channels between cays and onto the shelf of the Exuma Sound where most of the corals are found. It is suggested that this water is responsible for coral bleaching in the area. This study used hydrographic data collected over the shelf on the Exuma Sound to characterize the temperature, salinity, and density structure of hyperpycnal plumes after exiting the Great Bahama Bank. This was done to illustrate the behavior of the water as it is transported by currents to the shelf where it may cause coral bleaching. Findings showed that the warm hypersaline water sinks and spreads significant distances along the shelf, exposing the benthos to increases in temperature and salinity above normal conditions. Overall, the hyperpycnal bank water was a mechanism for coral bleaching.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Salinity, Water masses

Porter, J. W., S. K. Lewis and K. G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. *Limnology and Oceanography* **44**: 941-949.

The effects of fresh water intrusions on coral reefs were examined in the Florida Bay. The authors tested for significant effects of elevated temperature and salinity on coral production, respiration, and survival. Elevated temperatures produced reductions in photosynthesis, respiration, and net P:R ratios after 6 hours of exposure. Elevated salinities produced similar results after 30 hours. Exposure to both stressors produced a short-term mitigative interactive effect and was less stressful than the sum of the stressors acting independently for the response

variables measured. After 36 hours, the mitigative effect disappeared and corals exposed to both stressors did not survive. The multiple stressors model of salinity and temperature was able to explain recent declines in coral cover within Florida Bay and the Florida Keys.

Description of work: Laboratory. Location: Florida. Keywords: Coral reef, Temperature, Salinity, Multiple coral stressors, Photosynthesis, Respiration

Sakami, T. 2000. Effects of temperature, irradiance, salinity and inorganic nitrogen concentration on coral zooxanthellae in culture. *Fisheries Science* **66**: 1006-1013.

Cultured algae isolated from the hermatypic corals *Pocillopora damicornis* (strain P) and *Montipora verrucosa* (strain M) were tested to define effects of low light intensity, water temperature, salinity and inorganic nutrients. Maximum growth of strain P was observed at 32°C under all light intensities but higher photosystem 2 activity occurred at 28°C. Strain M was more affected by light intensity at all temperatures (24-36°C). Both strains had similar growth rates at low salinity (20-35 PSU) under irradiant light and moderate temperature. Overall, low irradiation and high temperature reduced tolerance against low salinity. Gross photosynthesis per cell was unaffected and cellular chlorophyll a content and cell density increased with ammonium enrichment up to 20 micromoles per day.

Description of work: Laboratory. Location: Japan. Keywords: Coral, Temperature, Salinity, Light intensity, Nutrients, Environmental stress, Zooxanthellae

Shinn, E., R. Reese and C. Reich. 1994. Fate and pathways of injection-well effluent in the Florida Keys. USGS Report 94-276 1-4.

Twenty four wells along the Florida Keys reef tract were sampled over a period of one year to determine changes in salinity, nitrogen, and phosphorus, as well as fecal coliform and fecal streptococcal bacteria. Increased levels of salinity and ammonia were found in offshore groundwater compared to surface waters. Increased levels of nitrogen (as NO<sub>2</sub> and NO<sub>3</sub>) and phosphorus were found in shallow onshore groundwater and, to a lesser extent, in the offshore groundwater. Possible sources of these nutrients were septic tanks and cesspools, as well as agricultural fertilizers. Fecal coliform and fecal streptococcal bacteria were found in three offshore wells located near the Lower Keys, and two shallow onshore wells (Key Largo). The authors stated that these findings are supporting evidence for offshore transport of water from Key Largo.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Nutrients, Salinity

Smith, S. V. and R. W. Buddemeier. 1992. Global change and coral reef ecosystems. *Annual Review of Ecology and Systematics* **23**: 89-118.

This paper reviews known or probable responses of coral reef ecosystems to global change. Topics discussed include: ecosystem roles and responses; reef responses to environmental variables; pathways of climate forcing; and large-scale, local, scientific, and institutional issues.

Description of work: Review. Location: None. Keywords: Coral reef systems, Global change, Carbon dioxide, Sedimentation, Sea level, Temperature, Light, Salinity, Nutrients

Swart, P. K. and R. Price. 2002. Origin of salinity variations in Florida Bay. *Limnology and Oceanography* **47**: 1234-1241.

A method of distinguishing the source of freshwater responsible for causing reductions in salinity along the coastal environment of South Florida is presented. The method uses the  $d^{18}O$  and  $dD$  of the water, taking into account fractionation effects due to precipitation and runoff. Everglades water has elevated  $d^{18}O$  and  $dD$  values because of evaporation. Water collected from stations in Florida Bay between 1993 and 1999 show that the major source of freshwater is from precipitation rather than runoff from the Everglades. Overall, this method allows sources of freshwater to be differentiated and can help determine the effectiveness of water management practices in the estuarine ecosystems of South Florida.

Description of work: Field. Location: Florida. Keywords: Salinity, Freshwater sources, Everglades, Precipitation

Swarzenski, P., J. Martin and J. Cable. 2001. Submarine ground-water discharge in upper Indian River Lagoon, Florida. *Water Resources Investigations Report 01-4011, USGS 1-10.*

Groundwater seepage rates were measured at 28 stations along the north end of the Indian River Lagoon, FL. Lagoon and interstitial water samples were also taken. Seepage rates into the Lagoon were determined using nutrients, chloride (Cl), conductivity, pH, temperature, dissolved oxygen, and various isotope ratios. Seepage rates were found to be 3-100 ml/m<sup>2</sup>/min during the dry season and 22-144 ml/m<sup>2</sup>/min during the rainy season. Seasonal differences may indicate that there is a connection between increased rainfall and increased groundwater seepage. Measurements of Cl indicated that most (95-99%) of the interstitial water was recycled lagoon water and did not originate from groundwater seepage. Nutrient concentrations were found to be 3-5 times higher in the seepage water over the lagoon, indicating that submarine groundwater discharge is important to the coastal nutrient budget.

Description of work: Field. Location: Indian River Lagoon, FL. Keywords: SGD, nutrients, salinity, temperature, pH

Wang, J. D., J. Luo and J. S. Ault. 2003. Flows, salinity, and some implications for larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science* **72**: 695-723.

Data on tides, wind and freshwater inflows were combined with physical and biological performance tests to develop a numerical model. The model was used to predict currents, residence times, salinity patterns and shrimp larval transport in S. Florida. Model predictions regarding tidal currents were found to be within 0.01 m/s of the observed values. Direct currents are controlled by tide while sub tidal currents are controlled by wind. Sub tidal currents were found to have a large effect on residence times. Model predictions of salinity and currents correlated well with data observations. The authors suggested that the model could be used to

estimate spatial shrimp population dynamics, making it useful for ecological risk assessment with regards to water management, Everglades restoration, and climate change.

Description of work: Field and Laboratory. Location: Biscayne Bay, Florida. Keywords: Inlet, Hydrodynamics, Salinity, Currents, Larval transport, Water management, SGD, Everglades Restoration

### **Sedimentation**

Acevedo, R., J. Morelock and R. A. Olivieri. 1989. Modification of coral reef zonation by terrigenous sediment stress. *Palaios* **4**: 92-100.

Four coral reefs near Puerto Rico were monitored for the effects of an influx of terrigenous sediment generated by resuspension of fine-grained sediments. Effects on coral cover was determined using percent cover by species, total cover, and number of colonies. Total coral cover was reduced near the source of terrigenous sediment influx and increased with distance from the source. Coral diversity also increased with distance from the source of sediment. This suggested the influx of sediment contributed to the deterioration of the reefs. Sediment-resistant coral species tolerated the sediment stress and their percent coral cover was constant. Overall effects of the sedimentation were partial or total burial of colonies, bleaching, and colonization by blue-green algae and sponges.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Terrigenous sediment plume, Coral stress

Alongi, D. M. and A. D. McKinnon. 2005. The cycling and fate of terrestrially-derived sediments and nutrients in the coastal zone of the Great Barrier Reef shelf. *Marine Pollution Bulletin*. **51**: 239-252.

This study examined the fate of terrestrially derived nutrients once they entered the Great Barrier Reef World Heritage Area (GBRWHA) coastal zone. The study concluded that most of that nutrients derived from terrigenous sources were metabolized by microbes in the GBRWHA coastal zone and not exported to the middle or outer shelf areas of the Great Barrier Reef. Nutrient budget calculations indicated that microbial mineralization rate exceeded the total nutrient load from river input and that insitu processes such as: N-fixation by benthic and pelagic microbes is an important source of nutrients to this system. The geography and oceanography of the coastal zone also restricted off shore transport of sediment and nutrients (i.e. Mangrove forests).

Description of work: Review. Location: Australia. Keywords: Nutrient, Coral, Sediment, Metabolism

Anthony, K. R. N. 1999. A tank system for studying benthic aquatic organisms at predictable

levels of turbidity and sedimentation: Case study examining coral growth. *Limnology and Oceanography* **44**: 1415-1422.

This study tests a flow-through tank system that allows exposure of benthic organisms to predictable concentrations of suspended particulate matter (SPM) and differing rates of sedimentation. The growth rates of *Goniastrea retiformis* and *Porites cylindrical* were monitored over an 8-week period. The effect of shading was also tested by using two light levels at low and high particle concentrations. The growth rate of *G. retiformis* increased as a function of SPM concentration (1-16 mg/L) while *P. cylindrical* was unaffected by particle load. Both species had reductions in growth under conditions of shade and 16 mg/L SPM concentration. The author hypothesized that the two species had different abilities to utilize SPM as a food source or different susceptibilities to SPM as a stress factor.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Sedimentation, Turbidity, Light, Shading, Suspended particulate matter (SPM)

Anthony, K. R. N. 2000. Enhanced particle-feeding capacity of corals on turbid reefs (Great Barrier Reef, Australia). *Coral Reefs* **19**: 59-67.

This study tested the hypothesis that corals from turbid inshore reefs in the Great Barrier Reef (GBR) lagoon have developed a greater capacity to feed on suspended sediment compared to species from less turbid nearshore and midshelf reefs. Two species common to the area, *Pocillopora damicornis* and *Acropora millepora*, were used for the experiment. The particle clearing rates of corals from turbid reefs were two-four times greater than those from less turbid and midshelf reefs. Sediment ingestion was a linear function of sediment load. Estimated carbon-14 assimilation varied between 50 and 80% and was maximized for midshelf *A. millepora*, indicating that heterotrophy is more efficient in oligotrophic habitats. Overall, coral species on turbid inshore reefs were 10-20 times more heterotrophic on suspended sediment than the same species on less turbid and midshelf reefs.

Description of work: Laboratory. Location: Australia. Keywords: Coral reef, Turbidity, Sedimentation, Particle clearing rate, Suspended sediment, Particle feeding

Anthony, K. R. N. and K. E. Fabricius. 2000. Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity. *Journal of Experimental Marine Biology and Ecology* **252**: 221-253.

Feeding rates on natural suspended particulate matter (SPM) can allow scleractinian corals to compensate for reduced phototrophy in turbid environments by using the SPM as a food source. Two corals were tested with differing phototrophic-heterotrophic capacities (*Goniastrea retiformis* and *Porites cylindrical*) and showed stress and growth optima at differing combinations of light and SPM amounts. Due to its phototrophic and heterotrophic plasticity, *G. retiformis* gained tissue and skeletal mass at all experimental levels of light and SPM. Due to lack of plasticity, *P. cylindrical* showed energy deficiency during high turbidity and these conditions appeared physiologically unsustainable for this species. Overall, plasticity offset stress from high particle loads.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Turbidity, Heterotrophy,



Autotrophy, Trophic plasticity, Sediment, Scleractinian coral

Babcock, R. and P. Davies. 1991. Effects of sedimentation on settlement of *Acropora millepora*. *Coral Reefs* **9**: 205-208.

This study investigated the effect of differing sedimentation rates on larval settlement and where larvae settle. The larvae of *Acropora millepora* were examined during varying rates of sedimentation, in aquaria. Settlement plates cut from faviid corals were placed in each tank horizontally and presented as upper, vertical and undersurface orientations. Findings showed that high sedimentation rates reduced the number of larvae settling on upper-surfaces, but the total number of larvae settled was not significantly affected by sedimentation.

Description of work: Location: Asian-Pacific. Keywords: Coral, Sedimentation, Larval Settlement

Bellwood, D. R., T. P. Hughes, C. Folke and M. Nystrom. 2004. Confronting the coral reef crisis. *Nature* **429**: 827-833.

This article reviewed temporal and geographic variations in the resilience of Caribbean coral reefs to human impacts like nutrient and sediment from runoff. The subtle signs of reef degradation have often gone unrecognized until a phase shift was well underway. The common views of coral reef management were reassessed by examining the role of critical functional groups, specifically the herbivores (bioeroders, scrapers and grazers). Functional groups were defined "as a collection of species that perform a similar function, irrespective of their taxonomic affinities". The species richness and taxonomic composition was used to determine the resilience of a functional group which dictates the range of tolerance to environmental changes. The number of functional groups present on a reef dictated its capacity to resist phase shifts. The following four recommendations were given for managing coral reef ecosystems: 1) the rate and size of No Take Zones should be increased dramatically; 2) the focus on NTZ's should not preclude resources being allocated to highly impacted and degraded reefs; 3) coral reef management policy should be more proactive and inclusive, by empowering users of the reefs as stewards; and 4) markets for reef resources need to be reformed to prevent exploitation of functional group species.

Description of work: Review. Location: Caribbean. Keywords: Coral, Resilience, Nutrient, Sediment, Phase Shift

Cortés, J. and M. J. Risk. 1985. A reef under siltation stress: Cahuita, Costa Rica. *Bulletin of Marine Science* **36**: 339-356.

The coral reef of Parque Nacional Cahuita, Costa Rica is an area of low live coral cover and species diversity. Sedimentation rates are high and a large amount of terrigenous material is trapped inside massive corals. Coral growth rates are low and inversely correlated with sediment resuspension rates. The authors suggest deforestation, which increased over the past 15 years, has increased siltation stress on the reef and reduced coral growth rates.

Description of work: Field. Location: Caribbean. Keywords: Coral reef, Sedimentation, Resuspension, Coral growth rate, Human impact

DHI Water and Environment, Inc. 2003. Modeling of wave, hydrodynamic and sediment transport processes in connection with the bypassing of sand at Port Everglades entrance. Status Report 89 pp.

This report discusses the work being done to carry out a numerical model in support of the ongoing feasibility study for the bypassing of sand across Port Everglades Inlet, Florida. Presented is the setup and calibration of the regional hydrodynamic model as well as summary of the setup of the local wave, hydrodynamic and sediment transport models for existing site conditions.

Description of work: Report. Location: Port Everglades, Florida. Keywords: Inlet, Hydrodynamic modeling, Wave modeling, Sediment transport modeling, Port Everglades, Sediment

Dodge, R. E., R. C. Aller and J. Thomson. 1974. Coral growth related to resuspension of bottom sediments. *Nature* **247**: 574-577.

The effects of resuspension of bottom sediments on the growth rate of *Montastrea annularis* in Discovery Bay, Jamaica was investigated. Growth rate of the coral was determined using a  $^{228}\text{Ra}$  technique and X radiography. There was found to be an inverse relationship between resuspension and coral growth; as resuspension increased, growth decreased going from east to west. The standard deviation of maximum and average growth decreased as resuspension increased. This indicated that high resuspension hinders coral growth as well as variability in growth. The ability of the coral to respond to less-limiting environmental conditions was therefore reduced by high resuspension rates.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Turbidity, Resuspension, Growth rate

Dustan, P. and J. C. Halas. 1987. Changes in the reef-coral community of Carysfort Reef, Key Largo, Florida: 1974 to 1982. *Coral Reefs* **6**: 91-106.

Data was collected from permanently marked transects in the Florida Keys to investigate coral reef changes over time. Results showed that populations between 0-9 meters mostly showed change as a result of physical disturbance while populations between 10-21 meters showed change as a result of sedimentation and disease.

Description of work: Field. Location: Florida. Keywords: Coral reef community, Physical disturbance, Sedimentation, Disease

Fabricius, K. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

This review focused on the direct effects of terrestrial runoff on coral reef communities at regional scales. The author identified inorganic nutrients and particulate matter as the most important contaminants of coral reefs on national and regional levels. Available data on the response of coral reef organisms to the following stressors was evaluated: increased dissolved inorganic nutrients; increased concentrations of particulate organic matter; light reduction; and increased sedimentation. The effects of these four stressors on hard coral colony calcification, tissue growth, symbiosis, reproduction and recruitment were evaluated. The author also looked at some other organisms that affected the abundance of hard corals, and their responses to the above stressors. These included bioeroders, macroalgae, filter feeders, octocorals, disease pathogens and predators. The author concluded that dissolved inorganic nutrients can reduce coral calcification rates, reduce fertilization success, and may promote species of macroalgae that compete for space with corals. Particulate organic matter and turbidity related light limitations have the same effect on heterotrophic filter feeders. Light limitation also reduces coral recruitment. Sedimentation also reduced growth and survival of corals, especially in recruitment and early life stages.

Description of work: Review. Location: None. Keywords: Nutrient, Sediment, Turbidity, Coral

Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

A review of current knowledge on the direct effects of terrestrial runoff, namely: the growth and survival of hard corals, coral reproduction and recruitment, and organisms that interact with coral communities are investigated. Response of each of these is evaluated against water quality parameters: increased dissolved inorganic nutrients, enrichment of organic matter, light reduction from turbidity, and increased sedimentation. Conclusions are that dissolved inorganic nutrients reduce coral calcification and fertilization rates and increase macroalgal abundance. Also, enrichment of particulate organic material enhances feeding rates and growth in some corals giving an advantage to compensate for light reduction (especially in high-flow settings). Lastly, turbidity light limitation reduces gross photosynthesis and reduces coral recruitment, and sedimentation reduces growth and survival of coral depending on species and sediment type.

Description of work: Review. Location: None. Keywords: Coral, Sedimentation, Nutrients, Turbidity, Coral reproduction, Recruitment, Light

Fabricius, K. E. and E. Wolanski. 2000. Rapid smothering of coral reef organisms by muddy marine snow. *Estuarine, Coastal and Shelf Science* **50**: 115-120.

A pilot study was presented to demonstrate the rapid detrimental effects on a near-shore coral (*Acropora* sp.) and coral-inhabiting barnacles (subfamily Pyrgomatidae) by suspended estuarine sediment when added to offshore water (oligotrophic: small aggregates) and nearshore waters (nutrient-rich: sediment forms large sticky aggregations of marine snow). The coral and barnacles were positioned in dishes, submerged in seawater and observed microscopically and by video recording. During the off-shore water treatment where aggregates were small in size (~50 micrometers) flocculation was minor and the organisms were able to clean themselves off at low siltation. During the near-shore water treatment, the suspended sticky aggregates of marine

snow resulted in the organism's forming thin coats of deposited floes and vigorously tried to clean themselves. After 5 minutes, the barnacle ceased moving and the coral polyps exuded a thick layer of mucus. Overall, it was suggested that the concentration of suspended mud in the water and extent of stickiness and flocculation can negatively affect reef benthos with only short exposure times.

Description of work: Laboratory. Location: Australia. Keywords: Coral reef, Marine snow, Sediment, Flocculation, Nutrient enrichment, Barnacle

Fichez, R., M. Adjeroud, U. Bozec, L. Breau, Y. Chancerelle, C. Chevillon, P. Douillet, J. Fernandez, P. Frouin, M. Kulbicki, B. Moreton, S. Ouillon, C. Payri, J. Perez, P. Sasal and J. Thebault. 2005. A review of selected indicators of particle, nutrient and metal inputs in coral reef lagoon systems. *Aquatic Living Resources* **18**: 125-147.

This paper is a review of the literature on indicators of several types of pollution to coral reefs, including particles, nutrients, and metals. The authors suggest that bioindicators be used in conjunction with abiotic indicators in order to more accurately predict the environmental response to inputs of particles, nutrients, and metals. They also suggest that these indicators be "calibrated" to each local system to provide more efficient environmental monitoring tools. This review illustrates a critical information gap in that there is very little scientific background regarding environmental indicators in tropical systems compared to temperate ones.

Description of work: Review. Location: None. Keywords: Coral, Eutrophication, Heavy metal, Nutrient, Sediment

Fisher, L. E. 1980. Annual update: Environmental assessment of the Broward County North Regional Outfall. 15 pp.

This annual update was done to determine if the presence of the North Broward (Pompano) outfall and its discharge has had any effect on the physical conditions of the surrounding environment. The Pompano outfall terminus is located 2.377 km offshore just south of the Hillsboro Inlet at a depth of 35 m. The "third reef" is 150 m west of the outfall terminus in 30 m of water and rises to 15 m over a distance of 100 m. Analysis of grain size distribution was done to determine if bottom sediment consistency has remained the unchanged. Sediment analysis was performed to look for the presence of selected trace metals, pesticides, and PCB's attributed to the discharge. Results of the grain size distribution analysis showed no significant difference between the control site and the outfall site. The chemical analysis of bottom sediments showed no pesticides or PCB's above the detection limits. Comparison of chemical analyses of the present study with one performed in 1978-79 shows slight increases for cadmium, chromium, lead, zinc, and nickel with no change or decreases for copper, iron and all chlorinated hydrocarbons. Chromium showed a significant decrease at the terminus of the outfall, lead at the terminus is twice the amount of other sites, and nickel shows a high concentration at the easternmost and deepest site. Overall, no changes have occurred in the consistency of bottom sediments between control and outfall samples. Differences (positive or negative) observed for the trace metals, pesticides, and PCB's may or may not be real; the variability may occur naturally in the sediment. No visual changes in the outfall environment were observed.

Description of work: Field and Laboratory. Location: Pompano, Florida. Keywords: Pompano

Outfall, Sediment, Pesticide, PCB, Trace metal, Cadmium, Chromium, Lead, Zinc, Nickel, Copper, Iron

Fokiel, P. L., E. K. Brown, A. Friedlander, S. K. Rodgers and W. R. Smith. 2004. Hawaii Coral Reef Assessment and Monitoring Program: Spatial patterns and temporal dynamics in reef coral communities. *Pacific Science* **58**: 159-174.

The Coral Reef Assessment and Monitoring Program (CRAMP) was established in 1999 to describe spatial and temporal variations in Hawaiian coral reefs in relation to natural and anthropogenic factors. This article reports the findings of the initial 3 year study period. The study examined 30 locations around the state. Permanent monitoring stations were established, one shallow and one deep, at each of the sites. Qualitative data on coral cover and diversity, macroalgae abundance, and fish populations was assembled from each site. This descriptive data was combined with the following ancillary variables: total population values; total area of adjacent watersheds; mean annual rainfall; offshore wave height; geologic age of the associated island and a ranking of the current level of reef management protection. Analysis of the data identified 6 major natural influences on coral reef community structure (depth, wave height, wave direction, island age, rugosity and sediment grain size). The dominant trend in anthropogenic influences was identified as extensive sedimentation resulting from human population activity in adjacent catchments.

Description of work: Field. Location: Hawaii. Keywords: CRAMP, Coral, Nutrient, Sediment

Gilmour, J. 1999. Experimental investigation into the effects of suspended sediment on fertilisation, larval survival and settlement in a scleractinian coral. *Marine Biology* **135**: 451-462.

Fertilization, settlement, and survival of larvae of the scleractinian coral *Acropora digitifera* were measured during high, low and control levels of suspended sedimentation. High- and low-sediment treatments significantly decreased fertilization, without inhibiting post-fertilization embryonic development. Larval survival and settlement were significantly reduced in high- and low-sediment treatments. Overall, larval recruitment to a population may be reduced in the presence of high levels of suspended sediment by affecting larval survival and settlement. Recruitment to adjacent populations may also be affected due to decreased fertilization success and increases of mortality at the affected site.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Sedimentation, Larval settlement, Fertilisation, Larval survival, Suspended sediment, Larval recruitment

Griffin, G. M. 1974. Case history of a typical dredge-fill project in the Northern Florida Keys - Effects on water clarity, sedimentation rates and biota. Harbor Branch Foundation, Inc. **Publication No. 33**: 67 pp.

This study provided data on the type, quantity, distribution, and effects of effluent generated by a dredge-fill project in the upper Florida Keys. Also included was a baseline study of the natural

water clarity throughout the upper Keys and sedimentological, physical, and biological parameters of the area. One major dredge-fill occurred during the term of the study, October 1972 to December 1973. A small coral patch reef 0.48 nautical miles NNE of the dredge site was monitored for overall health during and after the dredging. This dredging project resulted in no detectable impact on the coral patch reef or surrounding grass areas. Recommended criteria are presented to for consideration of future dredging projects.

Description of work: Field. Location: Florida. Keywords: Coral, Sedimentation, Dredging

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Harrington, L., K. Fabricius, G. Eaglesham and A. Negri. 2005. Synergistic effects of diuron and sedimentation on photosynthesis and survival of crustose coralline algae. *Marine Pollution Bulletin* **51**: 415-427.

The effects of sedimentation on three species of crustose coralline algae (CCA) were examined. The effects of diuron and sedimentation, separately and combined, was tested on one species of CCA. Results showed significant differences in sedimentation tolerance between the species. At environmentally relevant concentrations, diuron alone caused a decrease in photosynthesis of the CCA. At high diuron concentrations visible bleaching was observed. In these cases the effects were reversible when the samples were transferred to clean seawater. Bioassays using diuron and sediment caused a decrease in photosynthesis and irreversible damage to the CCA. Bleaching from chloroplast destruction and mortality was observed. The authors suggested that if the experimental conditions closely replicated field conditions then CCA could be severely affected by exposure to terrestrial runoff.

Description of work: Laboratory. Location: Australia. Keywords: Sediment, Herbicide, Pesticide,

## Coral

Hodgson, G. 1990. Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. *Coral Reefs* **9**: 41-43.

This study assessed the ability of coral planulae to settle on a horizontal glass surface covered with sediment to determine the relationship between percent of sediment cover and settlement rate. Larval settlement for all sediment treatments was significantly less than on the bare glass. 95% sediment cover prevented any settlement from taking place. No increase in settlement was observed when sediment cover was reduced from 90% to 50%. Overall, sediment that partially covers the substrate and is not directly harmful to adult coral colonies, could significantly reduce larval recruitment by preventing settlement.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Sedimentation, Larval settlement

Hubbard, D. K. 1986. Sedimentation as a control of reef development: St. Croix, U.S.V.I. *Coral Reefs* **5**: 117-125.

Sediment-transport data was collected in and around Salt River submarine canyon, St. Croix, U.S.V.I. over a 2-year period. Sediments generally moved in a westerly direction along the north shore of St. Croix. Sediment moved into the canyon at a higher rate over the eastern margin (47,000 kg/m-year) than the west wall (19,000 kg/m-year). Extensive reef growth is limited to the west wall as a result of this while the eastern margin is inhabited by gorgonians and a few sediment-tolerant corals. At Cane Bay, sedimentation rates were lower than at Salt River, with reef development accordingly greater. Sediment transport was one order of magnitude higher during storms than during fair weather. One hypothesis is that major hurricanes periodically flush the excess and keep long-term sediment influx and export in balance.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Sediment-transport rates, Meteorological impact

Hunte, W. and M. Wittenberg. 1992. Effects of eutrophication and sedimentation on juvenile corals. *Marine Biology* **114**: 625-631.

Settlement rates of juvenile scleractinian corals on artificial substrates on two eutrophic and two less eutrophic reefs in Barbados, West Indies. The reefs with high eutrophication experienced decreased coral recruits and number of recruiting species on the cement blocks. This could have resulted because of eutrophication or higher post-settlement mortality. Low settlement on eutrophic reefs could also have been due to lower local availability of larvae by fewer adult corals or lower reproductive rates of adult species. The ratio of coral recruits to adult coral abundance was lower on eutrophic reefs. This could have resulted from a lower probability of larvae settling because of the limited availability of suitable substrate. Colonization of non-coraline organisms was high on eutrophic reefs and unoccupied space was low, suggesting that suitable coral settlement substrate may be limiting on eutrophic reefs.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation,

## Eutrophication, Larvae settlement, Coral Recruitment

Hutchings, P., M. Peyrot-Clausade and A. Osnorno. 2005. Influence of land runoff on rates and agents of bioerosion of coral substrates. *Marine Pollution Bulletin* **51**: 438-447.

Effects of land runoff on bioerosion from sedimentation was investigated. Samples of recently killed colonies of *Porites* were placed at six sites on a cross shelf transect of Snapper Island at the entrance to the river and reef at the mouth of the Coral Sea. Bioerosion rates were monitored over four years. Inshore sites exhibited lower rates than other sites and offshore sites exhibited high rates due to grazing and internal bioerosion from macroborers (sponges, bivalves). Inshore sites were covered with silt, inhibiting colonization and growth of algae, resulting in lower grazing levels than offshore sites. Activity by macroborers between sites is thought to be due to the different levels of runoff. Overall, grazing rates were susceptible to change associated with anthropogenic impacts, not internal rates by boring macrofauna.

Description of work: Field. Location: Australia. Keywords: Coral, Sedimentation, Bioerosion, Runoff, Anthropogenic impact, Grazing

Larcombe, P., P. V. Ridd, A. Prytz and B. Wilson. 1995. Factors controlling suspended sediment on inner-shelf coral reefs, Townsville, Australia. *Coral Reefs* **14**: 163-171.

This study reports on 4 months of continuous water measurements of suspended sediment concentrations (SSCs) near inner-shelf fringing coral reefs of Cleveland Bay, N.E. Australia. These measurements, as well as wind, current, and wave data were then related to prevailing oceanographic and meteorological conditions. The temporal and spatial variation in the inner-shelf was high. Strong southeasterly winds generated swells within 1 km of the reef that produced SSCs of over 200 mg/l. However, the fringing reefs, SSCs were less than 5 mg/l and rarely exceeded 40 mg/l. Short-periods wind waves was the dominant control on the magnitude of near-bed SSCs at the reef sites, influencing the conditions for the coral communities. It is likely the flushing of the bays by tidal currents is important in preventing build-up of SSCs in the water around the coral reefs.

Description of work: Field. Location: Australia. Keywords: Coral reef, Suspended sediment concentrations (SSCs), Inner-shelf reef, Fringing reef, Oceanographic conditions

Larcombe, P. and K. J. Woolfe. 1999. Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. *Coral Reefs* **18**: 163-169.

Sediment supply over the past 200 years has increased due to human impact on the catchments in Australia. The Great Barrier Reef is under threat from increases in turbidity and sedimentation. By using geological data and information on sedimentary processes, this review postulates that turbidity levels and sediment accumulation at most reef areas will not increase as a result of these factors not being limited by sediment supply.

Description of work: Review. Location: Australia. Keywords: Coral reefs, Human impacts, Sedimentation, Turbidity



Leão, Z. M. A. N. and R. K. P. Kikuchi. 2005. A relic coral fauna threatened by global changes and human activities, Eastern Brazil. *Marine Pollution Bulletin* **51**: 599-611.

This study analyzes previous data collected of coral fauna from Holocene coral sections of two sites along the coast of Eastern Brazil. The processes responsible for the observed spatial and temporal changes in the presence of reef building coral species are discussed such as: periods of high turbidity, increasing human pressures (sedimentation, nutrification, pollution), tourism, and overfishing. The authors propose that if the current situation is paired with increases in sea surface temperature, that major reef building species in the area will soon become endangered. Description of work: Field. Location: South American Atlantic. Keywords: Coral, Human impact, Turbidity, Sedimentation, Nutrification, Pollution, Temperature

Lirman, D., B. Orlando, S. Maciá, D. Manzello, L. Kaufman, P. Biber and T. Jones. 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: Diversity, abundance, distribution, and environmental correlates. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**: 121-135.

The hardbottom habitat of Biscayne Bay make it a marginal environment for coral growth. An assessment of the Bay was performed to evaluate the coral populations present and investigate the factors that limit coral abundance, diversity, and distribution. Considering future changes in freshwater delivery into Biscayne Bay, due to the Everglades restoration, would affect salinity patterns and increase sediment loads which in turn are important to the abundance and distribution of corals in the area. Biscayne Bay contains a limited number of coral species. The physical characteristics of the basin make it a marginal environment for coral growth so the presence of *Siderastrea radians* and *Porites furcata* in Biscayne Bay indicate that these species are able to tolerate fluctuating conditions. Three factors, temperature, sedimentation, and salinity appeared to limit coral abundance, diversity and distribution in the bay. Sediment burial was shown experimentally to influence growth and mortality of *S. radians*. The salinity of the bay is influenced by freshwater inputs from canal, sheetflow, and groundwater sources that create a low mean salinity near-shore environment with large salinity fluctuation. Chronic exposure to low salinity was shown experimentally to decrease the growth of *S. radians*. The location of Biscayne Bay, downstream of the Everglades watershed, highlights the need to understand the relationship between the physical environment and the benthic community health.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral community, South Florida, Salinity, Sedimentation, Temperature, Hardbottom habitat, Everglades restoration

Loya, Y. 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rican corals. *Bulletin of Marine Science* **26**: 450-466.

This study correlated turbidity and sedimentation data obtained by other investigators to the coral community structure and species diversity of corals off the west coast of Puerto Rico. The area of study is heavily stressed by sediments from two rivers that discharge into the area. The East Reef on a steep slope (11-17-m depth) was compared to the flat West Reef (20-m depth). Coral diversity and coral cover were high at the East Reef while averages for turbidity and sedimentation were low. In contrast, coral diversity and coral cover at the West Reef were low

while the average turbidity and sedimentation levels were high. On both reefs, the species with the greatest efficiency of sediment rejection was *Montastrea cavernosa*. Other species on the West Reef that succeeded under the high turbidity and sedimentation conditions were: *Siderastrea radians*, *Siderastrea siderea*, *Diploria strigosa*, and *Meandrina meandrites*. Overall findings suggest that differences in the community structure between the East Reef and West Reef are the result of turbidity and sedimentation levels.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Turbidity, Coral stress, Diversity, Community structure

Macauley, J. M., J. K. Summers, V. D. Engle and L. C. Harwell. 2002. The ecological condition of South Florida estuaries. *Environmental Monitoring and Assessment* **75**: 253-269.

The ecological condition of South Florida estuaries was assessed based on regional monitoring during the summer of 1995. Samples were collected and measurements made on water and sediment quality, benthos, and fish tissue contaminants. Findings showed elevated concentrations of metals and pesticides in sediments and fish tissue with some levels exceeding guidance values. Dissolved oxygen levels of the bottom over 23-37% of the area were below state criteria. The study area spanned Anclote Key to the mouth of the Indian River. Based on a calculated index of ecological condition, 9% of the area exhibited degraded biology and impaired use.

Description of work: Field. Location: East coast, South Florida. Keywords: Inlet, Ecological condition, Environmental assessment, Water quality, Sediment, Benthos, Fish tissue, Metals, Pesticides, Oxygen

Manzello, D. and D. Lirman. 2003. The photosynthetic resilience of *Porites furcata* to salinity disturbance. *Coral Reefs* **22**: 537-540.

*Porites furcata* is one of the most abundant coral species in the shallow lagoon of Biscayne Bay, Florida. Variable salinity, temperature and high sedimentation make it a marginal environment for coral growth. *P. furcata* was tested to investigate its tolerance for salinity fluctuations to occupy this environment. This species had the capacity to survive sudden salinity changes without tissue mortality, maintained autotrophy during salinity stress, acclimated to short-term salinity changes, and rapidly recovered photosynthetic rates after a return to ambient salinity. Overall, *P. furcata* survived in a marginal reef environment.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Salinity, Photosynthetic response, Temperature, Sedimentation, Coral stress

Moss, A., J. Brodie and M. Furnas. 2005. Water quality guidelines for the Great Barrier Reef World Heritage Area: a basis for development and preliminary values. *Marine Pollution Bulletin*. **51**: 76-88.

This paper discussed how to establish local and regional water quality guidelines from existing federal guidelines. Nutrients, sediments and agricultural chemical impacts from adjacent catchments are addressed with respect to two types of water quality guidelines, pressure and

biological response indicators. Region specific guidelines based on the methodologies of ANZECC guidelines were proposed. Water temperature, <sup>15</sup>N, and diuron were specifically mentioned. It was concluded that currently there are not adequate indicators to determine if biological impacts on reefs are due to water quality alone in the GBRWHA. The authors made the following recommendations: develop indicators using a mix of stressors and compile adequate data sets to establish guidelines.

Description of work: Review. Location: Australia. Keywords: Nutrient, Sediment, Herbicide, Pesticide, Coral

Nugues, M. M. and C. M. Roberts. 2003a. Coral mortality and interaction with algae in relation to sedimentation. *Coral Reefs* **22**: 507-516.

Tissue mortality and radial growth measurements of *Colpophyllia natans* and *Siderastrea siderea* were taken over different sediment intensities. Results showed sedimentation facilitated algal overgrowth on corals however tissue mortality due to overgrowth was minor. Smothering and burial was the cause of the highest mortality and tissue loss of the coral; this also suppressed the regrowth of surviving adult colonies and new settlement through increased competition with algae.

Description of work: Field. Location: Caribbean. Keywords: Coral-algal competition, Sedimentation, Overgrowth, Phase shifts, Algal turfs, Coral mortality

Nugues, M. M. and C. M. Roberts. 2003b. Partial mortality in massive reef corals as an indicator of sediment stress on coral reefs. *Marine Pollution Bulletin* **46**: 314-323.

This study's objectives were: to describe the sedimentation rate and particle size-distribution of the surface sediment between sediment-exposed and control reefs, to examine partial mortality and fission on colonies of four common massive coral species, and to compare partial mortality and fission with changes in live coral cover to see if any changes reflect changes in total coral cover. In areas of high sedimentation (close to the river mouths), rates of partial mortality were higher than in areas farther away from sediment deposition. Fission frequency showed no significant trend. The percent change in coral cover over 4 years was negatively related to the partial mortality rate for all coral species. Therefore, partial mortality rates can reflect long-term temporal changes in coral communities. Overall, partial mortality measurements can be an effective mean of detecting sediment stress on reefs.

Description of work: Field. Location: Caribbean. Keywords: Coral reef, Sedimentation, Partial mortality, Sediment pollution, Coral cover

Ongley, E. D. 1996. Control of water pollution from agriculture. Food and Agriculture Organization of the United Nations **55**: 68 pp.

This publication addresses the agricultural operations that can contribute to water quality deterioration such as: sediments, pesticides, animal manurers, fertilizers and other sources of inorganic and organic matter. The Food and Agriculture Organization of the United Nations has

recognized the key role of water in agricultural development and implemented a Regular Programme on Water Resources Development and Management. Recommendations are given for control of sediment, fertilizer, and pesticide impacts on water quality.

Description of work: Review. Location: Canada. Keywords: Agricultural operations, Sediment, Pesticide, Fertilizer, Water Quality

Orpin, A. R., P. V. Ridd, S. Thomas, K. R. N. Anthony, P. Marshall and J. Oliver. 2004. Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. *Marine Pollution Bulletin* **49**: 602-612.

This study characterized the natural turbidity regime of an inshore fringing reef in the central Great Barrier Reef. A risk management scheme was outlined to minimize construction-related increases in turbidity. Comparisons between control and impact sites proved unusable for real-time management of turbidity risks. The authors suggested using a one standard deviation range from ambient conditions as a conservative upper limit of an acceptable increase in turbidity. Also, regional weather forecast is suggested for use in turbidity assessment, however this approach is limited in rough conditions when anthropogenic turbidity increases could be fatal to corals already stressed under natural conditions.

Description of work: Field. Location: Australia. Keywords: Coral reef, Turbidity, Sediment, Impact management, Coastal development, Coral stress, Weather impacts

Parnell, B. D. 1979. Environmental impact assessment of North Broward (Pompano) outfall. Environmental Quality Control Board 14 pp.

Following submission of the Iverson and Corcoran report of 1976, recommendations were made by the Water Pollution Committee of the Broward County Environmental Quality Control Board for continuing studies and formation of a program to monitor the North Broward County (Pompano) Outfall for at least one year. The objectives of this assessment were: to develop a program for studies to compare to the baseline study, photos of benthic habitats, analysis of bottom sediments, and measurement of current flow. Further objectives were added and included: identifying benthic macrofauna, determination of biological health status, geological studies of reefs at the outfall, and photos of study sites. This paper is an interim report of this study.

Description of work: Field. Location: Pompano Outfall. Keywords: Outfall, Environmental conditions, Effluent, Benthic habitat, Sediment analysis

Philipp, E. and K. Fabricius. 2003. Photophysiological stress in scleractinian corals in response to short-term sedimentation. *Journal of Experimental Marine Biology and Ecology* **287**: 57-78.

The effects of short-term sedimentation on 12 common coastal coral species was studied. Large amounts of sedimentation for short periods of time and colonies exposed to low amounts for prolonged periods of time killed exposed coral tissue. Recovery was possible from short-term, low-level sedimentation within <36 hours. Three of the twelve species tested were unaffected by

sedimentation. Overall, sediment deposition negatively affected the photosynthetic ability of tissues directly underneath the sediment, negatively affecting the viability of a coral. Photosynthetic ability of adjacent clean tissues was unaffected and continued to contribute to the coral community.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Sedimentation, Photophysiological stress, scleractinian coral

Rees, J., D. Setiapermana, V. Sharp, J. Weeks and T. Williams. 1999. Evaluation of the impacts of land-based contaminants on the benthic faunas of Jakarta Bay, Indonesia. *Oceanologica ACTA* **22**: 627-640.

Concentrations of Pb, Cu, Zn, Cr, and Ni were measured in seawater, suspended particulate matter (SPM) and sediments, as well as in coral tissues of *Goniopora lobata* and *Lobophyllia hemprichii* along a 72 km transect. Metal concentrations in seawater and SPM showed similar trends throughout the study transect with the highest concentrations being offshore. All metals in the sediments increased from offshore to inshore. The authors suggest that these results indicate a distribution controlled by seasonal hydrodynamics rather than spatial proximity to a pollution source. Very few measurements of metal concentrations in coral tissues were made because of sparse or very poor coral community structure. Those that were sampled showed no significant concentration differences between samples, but trends followed those of metal concentrations in seawater and SPM. However, coral cover and diversity increased significantly at 2 m sampling depth from inshore to offshore, suggesting that corals near shore are more stressed than those offshore. The authors suggest that the near shore corals were stressed by nutrient or organic pollutants, and not by heavy metals. Metal concentrations in offshore corals reflect seasonal fluctuations in dissolved metal in seawater.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Sediment, Heavy metal, Nutrient

Riegl, B. 1995. Effects of sand deposition on scleractinian and alcyonacean corals. *Marine Biology* **121**: 517-526.

Eight scleractinia species and five alcyonacea species were collected from Natal, South Africa to test their ability to withstand sand deposition. Scleractinian were active sediment shedders while alcyonacea were passive, relying on water motion and gravity. Clearing efficiency was dependent on corallum shape. Application of sand on the corals led to hydrostatic inflation of the polyps in the scleractinia and inflation of the entire colony in alcyonacea. Inflation remained continuous during sand application while tentacular motion ceased. In both scleractinia and alcyonacea, tissue necroses occurred after one week of continuous sand application. Entire colony death and partial bleaching occurred in alcyonacea only. Grain size of the sediment had no influence on clearing reaction or efficiency.

Description of work: Laboratory. Location: Africa. Keywords: Coral, Sedimentation, Clearing efficiency, Coral mortality, Tissue bleaching

Riegl, B. and G. M. Branch. 1995. Effects of sediment on the energy budgets of four

scleractinian (Bourne 1900) and five alcyonacean (Lamouroux 1816) corals. *Journal of Experimental Marine Biology and Ecology* **186**: 259-275.

Four scleractinia and five alcyonacea species were tested in the laboratory for effects of sedimentation and light conditions. Measurements of photosynthetic carbon production and respiration were taken to model daily energy budgets for the species. Loss of fixed carbon was measured through mucus production. Under conditions of sedimentation, productivity and respiration decreased. Production/respiration (P/R) ratios of all species were above 1 without exposure to sedimentation and dropped below 1 with sedimentation. Mucus output averaged 35% without sediment; this rose to 65% with sediment exposure. Overall, sedimentation affects coral metabolism by decreasing photosynthetic production while increasing respiration and carbon-loss through higher mucus output.

Description of work: Laboratory. Location: Africa. Keywords: Coral, Sedimentation, Coral stress, Energy budget, Photosynthetic carbon production, Respiration, Mucus production

Rogers, C. S. 1990. Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series* **62**: 185-202.

This review addresses the lack of ability to predict the consequences of increasing sediment concentrations and accumulation rates in tropical coastal areas. Topics discussed included: the effects of sedimentation at both an ecosystem and organismal level, the relationship between sedimentation coral and reef fishes, recovery after sediment stress, recommendations for monitoring sediment stress, predictions of the effects of coastal development on reefs, and future research needs.

Description of work: Review. Location: None. Keywords: Coral, Sedimentation, Dredging, Runoff, Growth, Distribution, Metabolism, Coral stress, Monitoring

Roy, R. E. 2004. Akumal's reefs: Stony coral communities along the developing Mexican Caribbean coastline. *Revista de Biología Tropical* **52**: 869-881.

The conditions of stony corals in the Akumal-area of the Yucatan coastline are characterized at two depths along an inferred sedimentation gradient with respect to species composition, live cover, colony density, relative exposure to turf algal-sediment mats (TAS), and for one species (*Diploria strigosa*, Dana, 1848), tissue regression rates in the presence of TAS mats. Transect surveys were conducted and showed that live stony coral cover, density and relative peripheral exposure of colonies to TAS mats were inversely related to an inferred sediment stress gradient at 13 m. In 2000, live stony coral cover had decreased by 40-50% at two sites from 1990. Half of this loss occurred between 1998 and 2000 during an outbreak of white plague disease. Overall, fringing reefs near Akumal have declined significantly between 1997 and 2000.

Description of work: Field. Location: Caribbean. Keywords: Coral, Turf-algal sediment mats, Disease, Live cover

Schleyer, M. H. and L. Celliers. 2003. Coral dominance at the reef-sediment interface in marginal coral communities at Sodwana Bay, South Africa. *Marine and Freshwater*

Research **54**: 967-972.

A coral community at Sodwana Bay, South Africa is subjected to sedimentation along the reef-sediment interface. Dominant taxa in the community are Alcyoniidae and Scleractinia. Included genera in decreasing order of abundance were: *Sinularia*, *Lobophytum*, *Sarcophyton*, *Montipora*, *Favia* and *Astreopora*. Sedimentation tolerance was investigated with Alcyoniidae being the most tolerant by way of their morphology and were the most prominent member of the community. Corals in the reef-sediment area were generally flat and have rigid colonies (*Lobophytum* and *Sinularia*); some have lobes to channel sediment movement, or are soft and pliable to easily shed particles from sedimentation.

Description of work: Field. Location: Africa. Keywords: Coral, Sedimentation, Marginal coral community

Smith, S. V. and R. W. Buddemeier. 1992. Global change and coral reef ecosystems. Annual Review of Ecology and Systematics **23**: 89-118.

This paper reviews known or probable responses of coral reef ecosystems to global change. Topics discussed include: ecosystem roles and responses; reef responses to environmental variables; pathways of climate forcing; and large-scale, local, scientific, and institutional issues. Description of work: Review. Location: None. Keywords: Coral reef systems, Global change, Carbon dioxide, Sedimentation, Sea level, Temperature, Light, Salinity, Nutrients

Stafford-Smith, M. G. 1993. Sediment-rejection efficiency of 22 species of Australian scleractinian corals. Marine Biology **115**: 229-243.

Interspecies variability in sediment-rejection efficiency was investigated *in-situ* for 22 Australian scleractinian coral species. Non-branching species showed a positive correlation between rejection rates and calice size. Rejection times were faster for fine grained sediment compared to coarse grained sediment at an influx of 200 mg/cm<sup>2</sup>. High water turbulence strongly influenced rejection rates of some species. Most species were able to clear sediment within 2 days. Of those that were unable to do this, *Favia stelligera* and *Leptoria phrygia* showed partial tissue death within 48 hours and *Gardineroseris planulata* did so within 6 days. Species able to tolerate sedimentation for at least 6 days exhibited extensive bleaching, but recovered after sediment removal. They included: *Montipora aequituberculata*, *Porites lobata* and *Porites lutea*. Sediment-rejection efficiency and sediment tolerance were not directly related.

Description of work: Field. Location: Australia. Keywords: Coral, Sedimentation, Water turbulence, Active-rejection, Morphology, Bleaching

Steven, A., M. Devlin, J. Brodie, M. Baer and M. Lourey (1995). Spatial influence and composition of river plumes in the central Great Barrier Reef. Downstream Effects of Land Use. Rockhampton, Australia, Great Barrier Reef Marine Park Authority: 4.

Szmant, A. M. and A. Forrester. 1995. Water column and sediment nitrogen and phosphorus

distribution patterns in the Florida Keys, USA. *Coral Reefs* **15**: 21-41.

As a part of the SEAKEYS program, the distribution of N, P and Chl a from near shore to offshore waters of the Florida reef tract was examined. Five transects were used in the upper keys, two in the middle keys and two in the lower keys. Water and sediment samples were collected over two year period. Sediment N concentrations were generally reduced by half from inshore to offshore, while P increased from inshore to offshore. Two spatial patterns were observed in the combined data for nutrient and Chl a concentrations in the sediment and water column. The first pattern was shown in the upper and lower keys transects. This pattern was characterized by elevated nutrients and chlorophyll concentrations inshore with a drop to oligotrophic levels within 1 km of shore. The second pattern was observed in the middle keys where water column nutrient levels were higher than the upper and lower keys study areas. There was also a much smaller decrease in water and sediment nutrient levels between the inshore and offshore sites. Upwelling may bring as much as 40 times the annual N load and 25 times the P load as compared to the total anthropogenic input to the Florida reef tract. The Florida reef waters studied were below the threshold values of DIN >0.1  $\mu\text{M}$ ,  $\text{PO}_4^{4-}$  >.01  $\mu\text{M}$  and Chl a > 0.5  $\mu\text{g/L}$ . Data from this study combined with other recent work suggested that the decline of the Florida coral reefs may be a part of a regional phenomenon associated with global climate change.

Description of work: Field. Location: Florida. Keywords: Nutrient, Coral, Sediment, DIN, P, Upwelling

Thomas, S., P. Ridd. 2005. Field assessment of innovative sensor for monitoring of sediment accumulation at inshore coral reefs. *Marine Pollution Bulletin* **51**: 470-480.

Short-lived events influencing sediment accumulation were investigated using a new method, a sediment accumulation sensor. Sites included fringing reefs along coastlines where anthropogenic development was taking place and sediment accumulation could be a threat. Accumulation increased dramatically at low tide while high rainfall and increased runoff had no increase in sediment accumulation. Accumulation rate and turbidity did not reveal any significant variations in sediment accumulation near coral related to high river discharge, high waves, currents, or high turbidity. Overall, accumulation rates were observed not to be directly related to suspended sediment concentration.

Description of work: Field. Location: Asian Pacific and Australia. Keywords: Coral, Sediment, Accumulation

Thomas, S., P. V. Ridd and G. Day. 2003. Turbidity regimes over fringing coral reefs near a mining site at Lihir Island, Papua New Guinea. *Marine Pollution Bulletin* **46**: 1006-1014.

A sediment transport survey was taken where mining operations involve disposal of waste rocks and soil into nearby water. Potential impacts of this practice were investigated to determine potential impacts on fringing reefs. Turbidity and sediment accumulation were measured over a period of 18 months. Measurements indicated that an extreme turbidity gradient persists and that observed zones conform with pre-operations impact predictions. Accumulation measurements



indicated no significant smothering or burial to any fringing reefs.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Sediment, Turbidity, Mining impact, Fringing coral reef

Walker, D. I. and R. F. G. Ormond. 1982. Coral death from sewage and phosphate pollution at Aqaba, Red Sea. *Marine Pollution Bulletin* **13**: 21-25.

The mortality rate of the coral *Stylophora pistillata* at a polluted coral reef site was compared to a control site. The test site was being polluted by primary treated sewage discharge and phosphate dust. 35 coral colonies were monitored in the polluted area. The mortality rate of the coral was found to be 4-5 times higher at the polluted site than at the control site. Glass plates were deployed to measure algal settlement and growth rates at each site. The growth of algae both on the coral and on glass plates was significantly greater at the polluted site. The authors suggest that the increase in algal biomass was only indirectly responsible for coral death and that the increased sediment trapped by the algae on the reef is the actual cause of coral death.

Description of work: Field. Location: Red Sea. Keywords: Eutrophication, Sediment, Coral, Nutrient

Wielgus, J., N. E. Chadwick-Furman and Z. Dubinsky. 2004. Coral cover and partial mortality on anthropogenically impacted coral reefs at Eilat, northern Red Sea. *Marine Pollution Bulletin* **48**: 248-253.

This study examined variations in coral cover and partial mortality at five sites exposed to varying levels of nutrients and inorganic sedimentation at Eilat, northern Red Sea. Photographs were taken to document changes over a 2-year period. Findings showed sites exposed to concentrations of total oxidized nitrogen (TON) between 0.4 and 0.6 micromoles had lower live coral cover and higher mortality than sites exposed to lower TON levels. Overall, levels of TON and the presence of SCUBA divers were significant variables of partial coral mortality while sedimentation rate was not a significant variable.

Description of work: Field. Location: Red Sea. Keywords: Coral, Sedimentation, Nutrients, Mortality, Total oxidized nitrogen

Wilkinson, C. R. 1999. Global and local threats to coral reef functioning and existence: review and predictions. *Marine and Freshwater Research* **50**: 867-878.

This review attempts to predict the consequences of direct and indirect anthropogenic factors affecting coral reefs as the human population and economic activity increase. The focus is on the past 10 years of research papers and reviews. Topics discussed include the effects of: latitude, depth, temperature, salinity, nutrient levels, geological disturbances, storms and other climactic disturbances, freshwater inundation, low tide exposure, predator and disease outbreak, increased sediment loads, organic and inorganic pollution, complex organic and heavy metal pollutants, over-exploitation, oil and petroleum products, engineering and military damage, increased carbon dioxide concentrations, increased UVB radiation, changes in sea level, and

weather. The short-term prediction includes reductions in the extent and biodiversity of coral reefs with disruption to cultures and economies dependent on them. The long-term prediction is more encouraging in that coral reefs are resilient and may stabilize as changes to the environment stabilize.

Description of work: Review. Location: None. Keywords: Coral, Anthropogenic factors, Stress, Sedimentation, Pollution, Bleaching, Mortality, Calcification, Carbon Dioxide, Sea Level

### **Submarine Groundwater Discharge**

Barile, P. J. 2004. Evidence of anthropogenic nitrogen enrichment of the littoral waters of east central Florida. *Journal of Coastal Research* **20**: 1237-1245.

This study analyzed water samples from the littoral coastline of Brevard and Indian River County, Florida. The quartz sand barrier island geology of the test area facilitated the formation of submarine groundwater discharges of barrier island aquifers, driven by tidal pumping.  $\delta^{15}\text{N}$  data was examined to differentiate the source of dissolved inorganic nitrogen to the system with respect to upwelling, sewage, nitrogen fixation, and fertilizer. Analysis of  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ ,  $\text{NO}_2^-$  and soluble reactive phosphorous concentrations showed that on average over half the dissolved inorganic nitrogen present was  $\text{NH}_4^+$  and the highest DIN concentrations were associated with rainfall events. The DIN values were in excess of threshold values required to support blooms of the red tide species *Karenia brevis* and various macroalgal species. The author suggested a link between anthropogenic nutrient availability and the presence of eutrophication-indicator macroalgal species. The  $\delta^{15}\text{N}$  values reported indicated that SGD is equally or more responsible for the delivery of sewage derived N to the system than any other source. However, analysis of fore reef macroalgae tissue also showed elevated values of  $\delta^{15}\text{N}$  concentrations associated with upwelling events.

Description of work: Field. Location: Florida. Keywords: Sewage, Nutrient, Coral, SGD  
Burnett, B. and J. Chanton. 2000. The role of groundwater in the nutrient budget of Florida Bay. 1-40.

Radon and methane concentrations were determined from samples collected from wells, solution holes, canals, and Florida Bay in an effort to determine patterns of groundwater to surface water interactions in the Bay. Seepage meters were also used to determine direct groundwater flux estimates. It was found that groundwater in the eastern area of the Bay supplied  $110 \pm 60$  mmol/m<sup>2</sup>/y of nitrogen and  $0.21 \pm 0.11$  mmol/m<sup>2</sup>/y of phosphorus to the Bay. Although these measurements are not uniformly found throughout the Bay, the authors suggested that submarine groundwater discharge is a significant source of nutrients to the Florida Bay.

Description of work: Field. Location: Florida. Keywords: SGD, nutrients

Burnett, W. C., H. Bokuniewicz, M. Huettel, W. S. Moore and M. Taniguchi. 2003.  
Groundwater and pore water inputs to the coastal zone. *Biogeochemistry*. **66**: 3-33.

This paper reviews submarine groundwater discharge (SGD) studies done from 1993 through 2003. The authors defined the process of submarine groundwater discharge and reviewed global flux estimates and biogeochemical consequences. SGD is defined as "any and all flow of water on continental margins from the seabed to the coastal ocean regardless of fluid composition or driving force." Three general approaches to assessing SGD were reviewed; these included modeling, physical measurement, and tracer techniques. Past groundwater flux estimates were usually calculated by making a number of assumptions and resulted in large uncertainty values. There is very little data available on the magnitude of SGD flow and exchange in coastal sediments. The authors suggest that new technology, and modeling strategies need to be developed in order to estimate fluxes and differentiate between the factors that influence SGD.

Description of work: Review. Location: USA. Keywords: Heavy metal, Coral, SGD, Coastal upwelling.

Corbett, D., W. Burnett and J. Chanton. 2001. Submarine groundwater discharge: and unseen yet potentially important coastal phenomenon. SGEB-54 by UF/IFAS 1-10.

Review of submarine groundwater discharge (SGD). Three techniques for measuring SGD are direct measurement through seepage meters, analytical observation using mathematical modeling, or tracer studies using radioactive or some other tracer substance. The authors suggest that SGD is an important source of nutrients, bacteria and other pollutants to the coastal ocean. The authors stated that any contaminant that groundwater is exposed to has the potential to become a marine contamination problem because groundwater eventually discharges into the coastal ocean. The authors also suggest that all future management guidelines must take into account the effects of SGD on coastal waters.

Description of work: Review. Location: Florida. Keywords: SGD

Corbett, D., J. Chanton, W. Burnett, K. Dillon, C. Rutowski and J. Fourqurean. 1999. Patterns of groundwater discharge into Florida Bay. *Limnology and Oceanography* **44**: 1045-1055.

Water samples were collected from wells, solution holes, canals, and Florida Bay. Samples were analyzed for radon and methane. Groundwater samples had higher concentrations of both tracers compared to surface water samples. Radon and methane were significantly correlated in all samples, indicating a common source which the authors suggest may be groundwater discharge. The authors also suggested that surface/groundwater interactions were largest along the shoreline on the Florida Bay side. Elevated nitrogen concentrations were also measured along the shoreline. Groundwater seepage was suggested as a possible source of this nitrogen enrichment.

Description of work: Field. Location: Florida Bay, FL. Keywords: SGD, Isotope tracers

Costa Jr., O. S., Z. M. A. N. Leao, M. Nimmo and M. J. Attrill. 2000. Nutrifcation impacts on coral reefs from northern Bahia, Brazil. *Hydrobiologia* **440**: 307-315.

The contamination of groundwater and its pathway to coastal waters and fringing coral reefs of

the east central coast of Brazil was examined. The study area included two transects from coastal lakes, across two sand barriers to the coral reefs. One transect was located in an urbanized area characterized with septic systems for waste disposal. The other transect crossed a geologically similar but uninhabited area. Pollution levels at the two sites were determined by analysis of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NO}_4^+$ ,  $\text{PO}_4$  and silicate. pH, salinity, temperature and fecal coliform concentrations were used as ground water tracers. Samples were taken in the dry and rainy seasons of 1997. Ecological assessment of the reef system was also conducted and quantified using data from 130 sites. All parameters were higher in the reef waters adjacent to the urbanized area. pH and fecal coliform values indicated human waste contamination of the ground water at the urbanized site. Silicate and salinity values suggested that eutrophication of coastal waters was occurring at the urbanized location. The reefs at the urbanized locations were found to be much more degraded than those adjacent to the uninhabited sites.

Description of work: Field. Location: South America. Keywords: Coral, Eutrophication, Sewage, SGD, Nutrient, Salinity, Temperature, pH, Fecal Coliform

Finkl, C. W. and R. H. Charlier. 2003. Sustainability of subtropical coastal zones in Southeastern Florida: Challenges for urbanized coastal environments threatened by development, pollution, water supply, and storm hazards. *Journal of Coastal Research* **19**: 934-943.

The authors address the intense urbanization along southeastern Florida from West Palm Beach to Miami and the effects to the Florida Reef Tract, the Biscayne Aquifer, submarine groundwater discharge, nutrient loading, coastal water quality, and tourism-related activities. Submarine groundwater discharge (SGD) causes an increase in nutrients to the Florida Reef Tract through the Biscayne Aquifer. This aquifer has one of the highest carbonate aquifer transmissivities in the world. Groundwater discharges in Palm Beach County are estimated at  $1,659 \times 10^6$  m<sup>3</sup>/yr. Nutrient fluxes from SGD to the coastal ocean are 5727 metric tons of phosphorous and 414 metric tons of nitrogen per year, while surface water contributions are 197 metric tons for phosphorous and 2471 metric tons for nitrogen per year. It is estimated that SGD is approximately 133% of surface water discharge. The authors suggest that the major source of these nutrients is sugar cane farming and that current approaches to remedy the situation will fail because they are focused on treating the symptoms not the cause of the problem. Topics addressed include: sustainability of beach systems and of agro-urban coastal environments; and the status quo and sustainability prognosis.

Description of work: Review. Location: Southeastern Florida. Keywords: Inlet, Environmental integrity, Submarine Groundwater discharge, Nutrient loading, Water quality, Remediation, Coastal Management, N, P

Finkl, C. W. and S. Krupa. 2003. Environmental impacts of coastal-plain activities on sandy beach systems: Hazards, perception and mitigation. *Journal of Coastal Research* **35**: 132-150.

A review of submarine groundwater discharge (SGD) as a source of nutrients to coastal areas in the Caribbean and Florida. The authors state that agricultural and urban activities lead to pollution of the surficial aquifers which in turn pollute the groundwater. The authors suggest

that this is a significant source of nutrients to the nearshore coastal regions and that it is steadily degrading the water quality. Increased concentrations of nutrients delivered via SGD can cause algal blooms and the reduction of water quality could lead to beach closings and loss of revenue in the future if left unchecked. Nutrient pollution from SGD is not easily visible and is often overlooked by the public in favor of preventing more obvious problems such as beach erosion. The authors suggest that seepage meter tests be conducted in order to quantify the problem as well as to draw attention to it.

Description of work: Review. Location: Caribbean and Florida. Keywords: SGD, Nutrients

Furnas, M., A. Mitchell, M. Skuza and J. Brodie. 2005. In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef lagoon. *Marine Pollution Bulletin* **51**: 253-265.

A review of phytoplankton growth rates in the Great Barrier Reef (GBR) found that ambient concentrations of N & P were not limiting. The dominant species was found to have potential population doubling rates of <1 day. Estimates of N & P demand by phytoplankton in nearshore waters showed that daily water column nutrient demand far exceeds the average daily amount supplied by benthic mineralization, river input, upwelling events and sewage discharges combined. The fact that nutrients are supplied in pulse events (river plumes) allows for the possibility that for short durations the input amounts may exceed phytoplankton demand. Nutrient limitation and grazing processes accounted for the lack of phytoplankton blooms in GBR waters. Ambient concentrations of N & P remained relatively constant because mineralization and uptake rates were balanced. In general only a small percentage of nutrients from nutrient pulse events reached the reefs or other benthic communities of the GBR. The bulk of the inorganic nutrient load were consumed by phytoplankton and converted to organic forms as they were passed up the food chain. These organic forms of nutrients were often dispersed over large areas and directly responsible for nutrient effects on benthic communities. Because of the rapid uptake of inorganic nutrients, measurements of dissolved inorganic nitrogen or dissolved inorganic phosphorous alone were not suitable for estimating nutrient availability. These values must be combined with accurate measurements of nutrient inputs, consumption, and turnover rates to quantify nutrient flow through the food chain to the point where it affects coral reefs.

Description of work: Review. Location: Australia. Keywords: Nutrient, DIN, DON, DIP, SGD, Upwelling, Mineralization, Benthic, Phytoplankton, Nitrogen, Phosphate

Garrison, G., C. Gleann and G. McMurtry. 2003. Measurement of submarine groundwater discharge in Kahana Bay, O'ahu, Hawai'i. *Limnology and Oceanography* **48**: 920-928.

Total submarine groundwater discharge (SGD) and nutrient concentrations were determined for Kahana Bay in O'ahu, HI. Conductivity, temperature, depth (CTD) profilers were used in conjunction with seepage meters, radioactive and natural tracers to locate and follow groundwater. The total SGD input was, on average,  $90 \times 10^6$  l/d. The average annual surface water runoff,  $90.7 \times 10^6$  l/d was given for comparison. The authors estimated that 16% of this SGD flux was due to terrestrial groundwater. Total dissolved phosphorus input from SGD was 500% greater than that of surface water runoff, and the total dissolved nitrogen flux from SGD

was 200% greater. The authors concluded that SGD is a significant source of nutrient input to Kahana Bay.

Description of work: Field. Location: Hawaii. Keywords: SGD

Kruczynski, W. L. 2002. Water quality concerns in the Florida Keys: Sources, effects, and solutions. In: Porter J.W., Porter K.G. (eds) *The Everglades, Florida Bay, and coral reefs of the Florida Keys: An ecosystem sourcebook* **CRC Press, Boca Raton: 827-881.**

The Florida Keys ecological diversity of the Florida Keys has made it a popular place to live and vacation. Human activities have negatively impacted the ecosystem and include from dredging and filling of seagrass beds and wetlands, construction of barriers to inhibit tidal flushing, and nutrient addition to the waters. Some physical ecological degradation is noticeable while some, such as water quality decline, may not be easily detected. This review summarizes available information of nearshore water quality to canals, basins, and water adjacent to the Keys. The data shows that nutrient loading from wastewater and stormwater has degraded water quality and that degraded water has negatively impacted nearshore communities. If nutrient loading continues, the ecological balance of the Florida Keys may be permanently altered.

Description of work: Review. Location: Florida. Keywords: Coral, Water Quality, Water system, Sewage, Groundwater, Surface water, Wastewater

Lapointe, B. E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. *Limnology and Oceanography* **42**: 1119-1131.

This study tested the hypothesis that the phase shift on Jamaican and Florida coral reefs to frondose macro algae dominance is mainly caused by nutrient enrichment. Analysis of water column nutrient concentration; salinity values; alkaline phosphate assays; tissue C:N:P ratios; and tissue  $^{15}\text{N}:$  $^{14}\text{N}$  ratios were included. It was found that nutrient limitation was responsible for setting the maximum algal standing crop on coral reefs. Nutrient enrichment bioassays on the chlorophytes *Chaetomorpha linum* from Jamaica and *Codium isthmocladum* from Florida were conducted. Salinity data combined with water column  $\text{NO}_3^-$  concentration data suggested that groundwater input was a source of nutrient enrichment of coral reefs in Discovery Bay, Jamaica and the east coast of Florida. Discovery Bay was characterized as a P-limited system. The macroalgal blooms on Florida reefs differed from those in Discovery Bay in that it is a N limited system. This was consistent with previous findings that N is more important in siliciclastic systems and P in carbonate-rich systems. High  $^{15}\text{N}:$  $^{14}\text{N}$  values found in macroalgal tissue sampled during the rainy season indicate that N from wastewater was a significant portion of nutrients in Florida coral reef waters. Data analysis from this study supported the theory of bottom-up control of macroalgal blooms at Discovery Bay and southeast Florida coral reefs. Description of work: Laboratory. Location: Caribbean, Florida. Keywords: DIN, C:N:P ratio, Submerged groundwater discharge, Nutrient, Coral

Lapointe, B. E. and M. W. Clark. 1992. Nutrient inputs from the watershed and coastal eutrophication in the Florida Keys. *Estuaries* **15**: 465-476.

The effects of nutrient inputs from septic tank leachant were analyzed in the Florida Keys coastal zone. Nutrient levels along a land-sea gradient across four ecosystems from inshore to offshore waters in the Florida Keys were measured. The ecosystems examined were, canals, seagrass meadows, patch reefs and offshore bank reefs. The authors found that septic tank leachant was increasing N and P concentrations to nearshore waters via manmade canal systems. Elevated  $\text{NH}_4^+$  concentrations were found in the canals and seagrass meadows but decreased with distance from shore. Soluble reactive phosphate and particulate phosphate concentrations followed the same pattern. Dissolved oxygen values increased with distance from land. During the summer, hypoxic conditions were observed at several Florida Bay stations. The study suggested that nutrient enriched submarine ground water discharge was intensifying coastal water eutrophication.

Description of work: Field. Location: Florida. Keywords: Eutrophication, Coral, Nutrient, SGD

Lapointe, B. E. and J. Oconnell. 1989. Nutrient-enhanced growth of *Cladophora prolifera* in Harrington Sound, Bermuda: Eutrophication of a confined, phosphorus-limited marine ecosystem. *Estuarine, Coastal and Shelf Science* **28**: 347-360.

Growth rate of the green algae *Cladophora* was measured to test the hypothesis that productivity is significantly enhanced by nutrient rich groundwater seepage. In-situ pore waters under algal mats were found to have reduced salinities, elevated levels of  $\text{NH}_4^+$  and high N:P ratios. The study utilized a flowing-seawater culture system to directly measure the nutrient dependence of *Cladophora* productivity. The data showed that enhanced growth rates were the result of N rich groundwater seepage and the efficient utilization of organo-phosphorus compounds by *Cladophora*.

Description of work: Laboratory. Location: Caribbean. Keywords: Nutrient, Coral, N, P, Groundwater

Moore, W. 2003. Sources and fluxes of submarine groundwater discharge delineated by radium isotopes. *Biogeochemistry* **66**: 75-93.

Radium isotope samples were collected from seepage meters, piezometers, surface, and deep waters along the northeastern Gulf of Mexico. Near shore samples were found to have a higher occurrence of all radium isotopes compared to offshore samples which varied in their isotope composition. Seepage meter and piezometer samples were found to be higher in radium by several orders of magnitude (2-3 for seepage meters and 1-4 for piezometers) compared to the overlying surface waters. The authors suggested that these observations indicate two separate sources of submarine groundwater discharge in the area, one shallow source from the surficial aquifer, and one from a deeper aquifer.

Description of work: Field. Location: Northeast Gulf of Mexico. Keywords: SGD, Radium Isotopes

Paerl, H. 1997. Coastal eutrophication and harmful algal blooms: Importance of atmospheric deposition and groundwater as "new" nitrogen and other nutrient sources. *Limnology and*

Oceanography **42**: 1154-1165.

Atmospheric deposition (AD) contributes 300-1,000+ mg/m<sup>2</sup>/yr of nitrogen (N) to coastal waters. When combined with groundwater (GW) inputs this accounts for 20-50% of total new N flux into the coastal zone. These sources may also contain other nutrients like iron and selenium, and may even contain some heavy metals. The author suggests that AD and GW inputs may be linked to an increase in harmful algal blooms (HABs). The author also suggests that future research be directed towards determining interactions of nutrients, biota, and physical oceanographic characteristics in order to better predict the causes of HABs.

Description of work: Review. Location: None. Keywords: SGD, Atmospheric Deposition

Paul, J., J. Rose, S. Jiang, X. Zhou, P. Cochran, C. Kellogg, J. Kang, D. Griffin, S. Farrah and J. Lukasik. 1996. Evidence for groundwater and surface marine water contamination by waste disposal wells in the Florida Keys. *Water Resources* **31**: 1448-1454.

Bacteriophages were used as tracers to monitor for wastewater in two injection wells in the Florida Keys, one simulated and one active well. Tracers were found in groundwater around both wells within 8 hrs of seeding. Tracers were found in surface waters around the simulated well 10 hrs after seeding and 53 hrs after seeding around the active well. The rates of movement of the tracers were highest near the simulated well (estimated 2.5-35 m/hr) compared to the active well (0.12-2 m/hr). The authors suggested that this difference was due to location and the increased impact of tidal pumping near the simulated well vs. the active well. The authors further concluded that if wastewater were introduced into a subsurface injection well it would quickly be mixed with surface waters and may contribute to nutrification of benthic reef communities and public health risks.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Bacteriophage

Paytan, A., G. Shellenbarger, J. Street, M. Gonneea, K. Davis, M. Young and W. Moore. 2006. Submarine groundwater discharge: An important source of new inorganic nitrogen to coral reef ecosystems. *Limnology and Oceanography* **51**: 343-348.

Radium isotope (Ra) activity, measured in disintegrations per minute, was used along with nutrient analysis to determine that submarine groundwater discharge (SGD) supplies nutrients, especially nitrogen (N) to offshore reefs. Ra and nutrient concentrations were higher in groundwater than in coastal waters by one to two orders of magnitude. The contribution from SGD was highly variable between samples due to the many factors that influence SGD, but there was a general concentration gradient for both nutrients and Ra with concentrations being highest near the shoreline.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Coral, N, Nutrients

Price, R., Z. Top, J. Happell and P. Swart. 2003. Use of tritium and helium to define groundwater flow conditions in Everglades National Park. *Water Resources Research* **39**: 13-1-13-12.



A three year study was conducted using tritium ( $^3\text{H}$ ) and helium ( $^3\text{He}$  and  $^4\text{He}$ ) as tracers to study the flow and age of groundwater in Everglades National Park. It was found that water in the upper 28 m of the surficial aquifer system (SAS) was younger, 30 yrs or less before present. Water below 28 m was older, originating 30 years or more before present. There was evidence of mixing at the 28 m interface. Younger water was consistently found below older water at one sampling location, Taylor Slough Bridge. The authors suggest that this may indicate that groundwater in this area flows towards the bottom of the Biscayne Aquifer. Evidence also suggested that there was increased vertical mixing in the seawater mixing zone, and that there was a potential for this brackish groundwater to discharge into overlying surface waters. Description of work: Field. Location: Everglades, FL. Keywords: SGD, Everglades, tritium, helium

Shinn, E., R. Reese and C. Reich. 1994. Fate and pathways of injection-well effluent in the Florida Keys. USGS Report 94-276 1-4.

Twenty four wells along the Florida Keys reef tract were sampled over a period of one year to determine changes in salinity, nitrogen, and phosphorus, as well as fecal coliform and fecal streptococcal bacteria. Increased levels of salinity and ammonia were found in offshore groundwater compared to surface waters. Increased levels of nitrogen (as  $\text{NO}_2$  and  $\text{NO}_3$ ) and phosphorus were found in shallow onshore groundwater and, to a lesser extent, in the offshore groundwater. Possible sources of these nutrients were septic tanks and cesspools, as well as agricultural fertilizers. Fecal coliform and fecal streptococcal bacteria were found in three offshore wells located near the Lower Keys, and two shallow onshore wells (Key Largo). The authors stated that these findings are supporting evidence for offshore transport of water from Key Largo.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Nutrients, Salinity

Simmons, G. 1992. Importance of submarine groundwater discharge and seawater cycling to material flux across sediment/water interfaces in marine environments. *Marine Ecology Progress Series* **84**: 173-184.

Submarine groundwater discharge (SGD) caused a movement of water and solutes across the sediment/water interface at least to a water depth of 30-35 m in the Florida Keys. Discharge values were  $8.91 \text{ m}^2 \text{ d}^{-1}$  for depth less than 27 m, and  $5.41 \text{ m}^2 \text{ d}^{-1}$  for depths between 27 and 39 m. The authors suggested that the most likely mechanism responsible for SGD into oceanic systems is sub tidal pumping and not land based hydraulic heads because lower salinity SGD was not detected.

Description of work: Field and Laboratory. Location: Florida Keys. Keywords: SGD, Coral

Swarzenski, P., B. Burnett, C. Reich, H. Dulaiova, T. Peterson and J. Meunier. 2004. Novel

geophysical and geochemical techniques used to study submarine groundwater discharge in Biscayne Bay, Florida. USGS Report 2004-3117 1-5.

A near continuous radon survey was combined with streaming resistivity profiling and electromagnetic seepage meters to study submarine groundwater discharge in Biscayne Bay, FL. Radon disintegrations per minute per liter were highest near Cutler Ridge (>11). Radon measurements indicated younger subsurface water masses. Electromagnetic seepage meters showed continuous groundwater discharge at the Cutler Ridge site, 10-50 cm/day. The authors suggested that this combined data indicates increased submarine groundwater discharge at several sites within the Bay, with the highest being Cutler Ridge.

Description of work: Field. Location: Biscayne Bay, FL. Keywords: SGD, Radium Isotopes, Radon Isotopes

Swarzenski, P., J. Martin and J. Cable. 2001. Submarine ground-water discharge in upper Indian River Lagoon, Florida. Water Resources Investigations Report 01-4011, USGS 1-10.

Groundwater seepage rates were measured at 28 stations along the north end of the Indian River Lagoon, FL. Lagoon and interstitial water samples were also taken. Seepage rates into the Lagoon were determined using nutrients, chloride (Cl), conductivity, pH, temperature, dissolved oxygen, and various isotope ratios. Seepage rates were found to be 3-100 ml/m<sup>2</sup>/min during the dry season and 22-144 ml/m<sup>2</sup>/min during the rainy season. Seasonal differences may indicate that there is a connection between increased rainfall and increased groundwater seepage. Measurements of Cl indicated that most (95-99%) of the interstitial water was recycled lagoon water and did not originate from groundwater seepage. Nutrient concentrations were found to be 3-5 times higher in the seepage water over the lagoon, indicating that submarine groundwater discharge is important to the coastal nutrient budget.

Description of work: Field. Location: Indian River Lagoon, FL. Keywords: SGD, nutrients, salinity, temperature, pH

Wang, J. D., J. Luo and J. S. Ault. 2003. Flows, salinity, and some implications for larval transport in South Biscayne Bay, Florida. *Bulletin of Marine Science* **72**: 695-723.

Data on tides, wind and freshwater inflows were combined with physical and biological performance tests to develop a numerical model. The model was used to predict currents, residence times, salinity patterns and shrimp larval transport in S. Florida. Model predictions regarding tidal currents were found to be within 0.01 m/s of the observed values. Direct currents are controlled by tide while sub tidal currents are controlled by wind. Sub tidal currents were found to have a large effect on residence times. Model predictions of salinity and currents correlated well with data observations. The authors suggested that the model could be used to estimate spatial shrimp population dynamics, making it useful for ecological risk assessment with regards to water management, Everglades restoration, and climate change.

Description of work: Field and Laboratory. Location: Biscayne Bay, Florida. Keywords: Inlet, Hydrodynamics, Salinity, Currents, Larval transport, Water management, SGD, Everglades

## Restoration

### Temperature

Abramovitch-Gottlib, L. D. Katoshevski and R. Vago. 2003. Responses of *Stylophora pistillata* and *Millepora dichotoma* to seawater temperature elevation. *Bulletin of Marine Science* **73**: 745-755.

The scleractinian coral *Stylophora pistillata* and the hydrocoral *Millepora dichotoma* were tested for their physiological responses to elevated seawater temperatures. At 34°C zooxanthellae densities of *M. dichotoma* decreased significantly whereas densities of *S. pistillata* increased because of different tolerance mechanisms to elevated temperature. Both species at 34°C showed chlorophyll *a* concentrations increased and chlorophyll *c* concentrations decreased. Seawater temperatures above 26°C caused decreased calcification rates. Overall findings showed the critical point for zooxanthellae-host association was 31.1°C and any higher than this was lethal.

Description of work: Laboratory. Location: Middle East. Keywords: Coral, Critical temperature, Zooxanthellae, Chlorophyll, Calcification

Antonius, A. and B. Riegl. 1998. Coral diseases and *Drupella cornus* invasion in the Red Sea. *Coral Reefs* **17**: 48.

A large scale ecological investigation of coral reefs in the Gulf of Aqaba in 1996 surveyed 25 reefs. Most were diagnosed as in "good health" however the corals on one reef were suffering from a population outbreak of *Drupella cornus*, a corallivorous snail, and an outbreak of White Syndromes (White Band Disease, Tissue Bleaching, and Shut-Down-Reaction). *Acropora hemprichi*, the most abundant reef-building species in the area, suffered the highest mortality. There appeared to be a strong correlation between snail abundance and disease prevalence. It is unclear if massive coral die-offs due to White Syndromes attract or benefit *Drupella cornus* or whether the presence of the snail promotes an outbreak of White Syndromes among the corals. Description of work: Field. Location: Red Sea. Keywords: Coral disease, White Syndromes, White Band Disease, Tissue bleaching, Shut-Down-Reaction, Corallivorous snail

Aronson, R. B., W. F. Precht, M. A. Toscano and K. H. Koltes. 2002. The 1998 bleaching event and its aftermath on a coral reef in Belize. *Marine Biology* **141**: 435-447.

A massive coral bleaching event took place along the Belizean barrier reef as a result of elevated sea temperatures. Fore-reef habitats of the outer barrier and offshore platforms showed signs of recovery in 1999, but reefs in the central shelf lagoon had a catastrophic die-off. From 18 September to 1 October of 1998, temperatures around lagoon reefs averaged an increase of 2.2°C with a maximum increase of 4.0°C. A dominant species, *Agaricia tenuifolia*, was nearly eradicated. New open space on the substrate allowed room for colonization, but coral cover and recruitment remained low. High sea urchin populations kept macroalgae levels low, but the encrusting sponge, *Chondrilla cf. nucula* increased in the area thereby depressing coral

populations and prevented the recovery of *A. tenuifolia*.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Colonization, Recruitment

Baker, A. C., C. J. Starger, T. R. McClanahan and P. W. Glynn. 2004. Corals' adaptive response to climate change. *Nature* **430**: 741.

Scleractinian corals with algal symbionts (genus *Symbiodinium*) were surveyed to determine if thermally tolerant symbionts were abundant on reefs that have been affected by climate change. Molecular surveys were done and corals were differentiated by restriction-fragment length polymorphisms in their symbionts' large-subunit ribosomal DNA. This information was used to distinguish the *Symbiodinium* into clades A, C, or D. Results indicated that corals containing thermally tolerant *Symbiodinium* in clade D were more abundant on reefs after episodes of bleaching and mortality. Also, surviving coral symbioses more closely resembled those found in high-temperature environments.

Description of work: Field. Location: Africa, Caribbean, Red Sea, Middle East. Keywords: Coral, Thermal tolerance, Climate change, Temperature, Bleaching, Algal symbionts, Zooxanthellae

Ben-Haim, Y. and E. Rosenberg. 2002. A novel *Vibrio sp.* Pathogen of the coral *Pocillopora damicornis*. *Marine Biology* **141**: 47-55.

A coral pathogen, *Vibrio coralyticus*, was isolated from the diseased tissue of *Pocillopora damicornis*. *V. coralyticus* was injected into the seawater surrounding live corals or directly onto coral tissue. At 29°C lysis began as small white spots, rapidly spreading so that the entire tissue was destroyed after 2 weeks. Placing a healthy coral next to a diseased coral caused lysis of the healthy coral in 2-4 days, showing this disease was contagious. Temperature was critical for the infectious process; infection/lysis occurred rapidly at 27-29°C, slowly at 26°C, and was not observed at 25°C. Overall, the presence of this pathogen in seawater surrounding a coral reef led to tissue destruction when seawater temperature was increased.

Description of work: Laboratory. Location: Middle East. Keywords: Coral disease, *Vibrio coralyticus*, Coral pathogen, Temperature

Berkelmans, R. and J. K. Oliver. 1999. Large-scale bleaching of corals on the Great Barrier Reef. *Coral Reefs* **18**: 55-60.

The most intense and extensive bleaching event of the Great Barrier Reef occurred in 1998. This major bleaching event was due to a combination of elevated sea temperatures and high solar radiation further exacerbated by low salinity from heavy rains and river flooding.

Description of work: Field. Location: Australia. Keywords: Coral, Bleaching, Temperature, Mortality

Berkelmans, R. and B. L. Willis. 1999. Seasonal and local spatial patterns in the upper thermal

limits of corals on the inshore Central Great Barrier Reef. *Coral Reefs* **18**: 219-228.

Maximum tolerable temperatures were determined for local corals on the Central Great Barrier Reef (GBR) in the absence of additional stressors (high light). Temperature tolerances were investigated between winter and summer on corals from both the reef slope and reef flat areas. A 5-day 50% bleaching threshold was used to determine upper limits. *Acropora formosa* had a 5-day 50% bleaching threshold between 31-32°C in the summer (2-3°C higher than mean summer temperatures). Summer bleaching thresholds for *Pocillopora damicornis* and *Acropora elseyi* were between 32-33°C. The winter bleaching threshold for *Pocillopora damicornis* was one degree lower than summer, indicating seasonal acclimatization of the species. It was found that bleaching responses were delayed up to a month following thermal stress, implying timing issues with identifying stressful conditions during natural bleaching events.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Bleaching, Temperature, Acclimatisation, Upper thermal limit

Bhagooli, R. and M. Hidaka. 2004. Release of zooxanthellae with intact photosynthetic activity by the coral *Galaxea fascicularis* in response to high temperature stress. *Marine Biology* **145**: 329-337.

Photosystem II functioning was compared to overall photosynthetic ability of retained and released zooxanthellae (bleaching) from *Galaxea fascicularis* when exposed to high temperature stress. There was no difference in photochemical efficiency of photosystem II between zooxanthellae isolated from the polyps exposed to high temperature (30 or 32°C for 24 hr) and those released from the polyps during the stress treatment. Overall findings showed that zooxanthellae were expelled non-selectively regardless of photosynthetic ability when exposed to high temperature stress. Moreover, the coral host suffered physiological damage which resulted in zooxanthellae release.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Bleaching, Temperature, Zooxanthellae, Photosynthetic activity, Photosystem 2, PAM fluorometry

Black, N. A., R. Voellmy and A. M. Szmant. 1995. Heat shock protein induction in *Montastraea faveolata* and *Aiptasia pallida* exposed to elevated temperatures. *The Biological Bulletin* **188**: 234-240.

This objective of this study was to determine if the Caribbean reef coral *Montastraea faveolata* produces heat shock proteins (hsps). Colonies of this coral were subjected to exposure of high temperature followed by recovery periods at a control temperature, then tested for elevation of hsp synthesis. Several hsps were found in both *Montastraea faveolata* and *Aiptasia pallida* after exposure to elevated temperature and each species produced its own characteristic set of hsps.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Temperature stress, Bleaching, Heat shock protein

Brown, B. E. 1997. Coral bleaching: Causes and consequences. *Coral Reefs* **16**: S129-S138.

The author presents a general review of recently acquired data on coral bleaching. The focus is on rising sea temperature and irradiance-induced bleaching. Mechanisms behind which bleaching occurs resulting in degradation of zooxanthellae, release of zooxanthellae, and release of algae within host cells is also investigated. One suggestion is that phenotypic responses of both corals and zooxanthellae may be significant in determining how bleaching occurs. Overall, interactions between elevated sea temperature and increased irradiance are both major factors in determining the mortality as well as the ability of reefs to recover.

Description of work: Review. Location: None. Keywords: Coral, Bleaching, Solar irradiance, Temperature, Zooxanthellae

Brown, B. E., R. P. Dunne, T. P. Scoffin and M. D. A. Le Tissier. 1994. Solar damage in intertidal corals. *Marine Ecology Progress Series* **105**: 219-230.

Solar irradiance has been cited as a possible cause of bleaching in corals, however evidence of solar involvement in naturally occurring bleaching is largely conjecture. Natural occurrences of bleaching in massive intertidal corals at Phuket, Thailand were recorded. Tidal data, sun track analysis, and solar irradiance measurements were used to show that this bleaching directly corresponds to sun altitude and azimuth. Findings showed bleaching is induced during periods of subaerial exposure and high sun altitude and irradiance. Also, on-site measurements of solar irradiance mitigate against the biologically damaging effect of shorter wavelength ultraviolet radiation (UVR) as a major causative factor.

Description of work: Location: Asian-Pacific. Keywords: Coral, Bleaching, Irradiance, Light, Solar radiation, UVR

Carricart-Ganivet, J. P. 2004. Sea surface temperature and the growth of the West Atlantic reef-building coral *Montastraea annularis*. *Journal of Experimental Marine Biology and Ecology* **302**: 249-260.

The relationship between sea surface temperature (SST) and annual growth characteristics (density, extension rate, and calcification rate) were analyzed in the Caribbean coral, *Montastraea annularis*. Colonies were collected from the Gulf of Mexico and the Caribbean Sea for comparison. During increased SST at both sites, calcification rate and skeletal density increased, while extension rate decreased. Zero calcification was projected to occur at 23.7°C in Gulf of Mexico corals and 25.5°C in Caribbean corals. This indicated that Gulf of Mexico corals were adapted to growth at lower minimum and average annual SST than Caribbean corals. At lower SST, corals at both locations had extension rates higher than at increased SSTs. It was suggested the corals put more calcification resources into extension and less into skeletal density at lower SSTs.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Sea surface temperature, Density, Extension rate, Calcification rate

Cervino, J. M., R. Hayes, T. J. Goreau and G. W. Smith. 2004a. Zooxanthellae regulation in yellow blotch/band and other coral diseases contrasted with temperature related bleaching: *in situ* destruction vs. expulsion. *Symbiosis* **37**: 63-85.

This study investigated the differences between symbiotic zooxanthellae expulsion induced by temperature/related bleaching, and the loss of symbiotic zooxanthellae in corals that were stressed by pathogen-induced diseases, specifically, yellow blotch/band disease (YBD). Changes in the algae of YBD-infected corals were different than changes in temperature bleached corals. In disease-infected corals, no evidence existed of zooxanthellae in the mucus, unlike thermal bleaching where zooxanthellae were evident in the coral surface layer. Zooxanthellae isolated from corals inoculated with YBD showed a 96% decrease in chlorophyll *a* pigments and a 90% decrease in mitotic cell division when compared to controls. So, YBD pathogens target the zooxanthellae and compromise cytoplasmic and organelle integrity, leaving the host tissue intact. Overall, this study suggested that YBD is a coral disease of the symbiotic zooxanthellae and not a disease of the coral host. This study also documented for the first time the discovery of viral-like particles (VLPs) found in the symbiotic algae in *Montastraea* spp. with YBD.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Coral disease, Yellow blotch/band, Zooxanthellae, Pathogen-induced disease

Cervino, J. M., R. L. Hayes, S. W. Polson, S. C. Polson, T. J. Goreau, R. J. Martinez and G. W. Smith. 2004b. Relationship of *Vibrio* species infection and elevated temperatures to Yellow Blotch/Band disease in Caribbean corals. *Applied and Environmental Microbiology* **70**: 6855-6864.

Yellow blotch/band disease (YBD) which affects the major reef-building *Montastrea* spp. corals of the Caribbean was investigated. Bacteria isolated from diseased corals and inoculated onto healthy ones caused signs of YBD to appear. The rRNA genes of the disease were sequenced and found to correspond to four *Vibrio* spp. Increases in water temperatures resulted in an increased spreading rate of YBD on inoculated corals, therefore increasing coral mortality. During high temperatures, infected corals had 50% less zooxanthellae, 80% lower division rates, and a 75% decrease in chlorophyll *a* and *c* pigments compared to controls. Overall, YBD didn't appear to produce the same physiological response as bleaching, it primarily affected the symbiotic algae rather than coral tissue.

Description of work: Laboratory. Location: Florida and Caribbean. Keywords: Coral disease, *Vibrio*, Temperature, Yellow Blotch/Band disease, Bacteria, Zooxanthellae, Bleaching

Coles, S. L. 1975. A comparison of effects of elevated temperature versus temperature fluctuations on reef corals at Kahe Point, Oahu. *Pacific Science* **29**: 15-18.

The effluent discharge from the Hawaiian Electric Company Kahe Generating Station, Oahu, Hawaii was monitored for 5 months in regards to the mortality of *Pocillopora meandrina*, the most thermally sensitive species in the area. Mortality was about the same in both the area of maximum thermal enrichment (1-2 meters depth) and in an area more distant from the discharge (4-5 meters depth). Sublethal damage (zooxanthellae loss) to the coral was more prevalent in the area of discharge. Bottom temperatures around the discharge area varied between 3-4°C within minute periods at low tide; corals rarely encountered temperatures exceeding 31°C. Overall, indications were that upper absolute temperatures resulted in greater coral damage than short-

term temperature shocks near upper lethal limits.

Description of work: Field. Location: Hawaii. Keywords: Coral, Thermal Effluent, Temperature, Upper temperature limit

Coles, S. L. and Y. H. Fadlallah. 1991. Reef coral survival and mortality at low temperatures in the Arabian Gulf: New species-specific lower temperature limits. *Coral Reefs* **9**: 231-237.

Cold fronts passing over the Arabian Gulf from December 1988 to March 1989 resulted in the longest period of sustained low water temperature ever recorded in a coral reef area.

Temperatures during this periods provided new estimates of lower thermal limits for coral survival. At the northern site, high mortality of *Acopora pharaonis* and *Platygyra daedalea* occurred where temperatures fell below 11.5°C (normal average of 23°C) on four consecutive days and mean daily temperatures were 13°C or less for more than 30 days. *Porites compressa*, the primary reef-builder in the area, only showed sub-lethal effects and appeared normal after 6 months. At the southern site, where temperatures fell below 12.5°C for two consecutive days and mean temperatures were 14°C or less, showed no coral reef damage.

Description of work: Field. Location: Middle East. Keywords: Coral, Low temperature, Bleaching, Thermal limit

Coles, S. L., P. I. Jokiel and C. R. Lewis. 1976. Thermal tolerance in tropical versus subtropical Pacific reef corals. *Pacific Science* **30**: 159-166.

The intensity and duration of maximum natural temperature elevations among living corals were measured on both tropical and subtropical reefs. These temperatures were compared to the upper thermal limits of the corals under identical experimental conditions. Caribbean corals survived *in situ* temperatures of 34°C, however 32°C was found to be lethal to Hawaiian corals.

Laboratory findings indicated the upper thermal limits of Hawaiian corals to be about 2°C higher than the Caribbean corals. In other words, there is a 2°C difference in temperature tolerance between Hawaiian and tropical corals. Overall, the difference of ambient temperatures between the two geographic areas led to different coral thermal tolerance.

Description of work: Field and Laboratory. Location: Hawaii and Caribbean. Keywords: Coral, Temperature, Upper thermal limit, Tropical coral, Subtropical coral

Coles, S. L. and P. L. Jokiel. 1977. Effects of temperature on photosynthesis and respiration in hermatypic corals. *Marine Biology* **43**: 209-216.

The corals *Pocillopora damicornis*, *Montipora verrucosa*, *Porites compressa* Dana, and *Fungia scutaria* Lamark were studied. Findings show coral metabolism to be closely adapted to ambient water temperatures. Tropical corals showed greater primary production at elevated temperatures than subtropical varieties of the same species. P:R ratios were negatively related with temperatures between 18-31°C for subtropical corals while tropical corals showed a curvilinear P:R relationship. Tropical specimens at temperatures above 25°C showed lethal temperatures for these corals to be 2-5°C higher than for subtropical (tropical lethal limit 34-35°C, subtropical



lethal limit 31-32°C). Overall, both tropical and subtropical species were adapted to their normal ambient water temperature conditions.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Temperature, Photosynthesis, Respiration, Lethal limit, Tropical coral, subtropical coral

Coles, S. L. and P. L. Jokiel. 1978. Synergistic effects of temperature, salinity and light on the hermatypic coral *Montipora verrucosa*. *Marine Biology* **49**: 187-195.

Temperature tolerance of the hermatypic coral *Montipora verrucosa* was investigated. Findings showed the coral was affected by changes in salinity and light. Low salinity reduced its ability to survive short-term exposure to high temperatures (32-33°C). High natural light intensity worsened damage at a high temperatures. High light intensity caused loss of zooxanthellae pigment, increased mortality, reduced carbon fixation and decreased growth rate at both upper (increase of 4-5°C) and lower temperature limits in the long-term. Synergistic effects between parameters as well as the direct effect of each individual variable were important in determining environmental tolerance of the coral species.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Temperature, Salinity, Light intensity, Zooxanthellae, Mortality, Carbon fixation, Sublethal temperature

Costa Jr., O. S., Z. M. A. N. Leao, M. Nimmo and M. J. Attrill. 2000. Nutrifcation impacts on coral reefs from northern Bahia, Brazil. *Hydrobiologia* **440**: 307-315.

The contamination of groundwater and its pathway to coastal waters and fringing coral reefs of the east central coast of Brazil was examined. The study area included two transects from coastal lakes, across two sand barriers to the coral reefs. One transect was located in an urbanized area characterized with septic systems for waste disposal. The other transect crossed a geologically similar but uninhabited area. Pollution levels at the two sites were determined by analysis of  $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NO}_4^+$ ,  $\text{PO}_4$  and silicate. pH, salinity, temperature and fecal coliform concentrations were used as ground water tracers. Samples were taken in the dry and rainy seasons of 1997. Ecological assessment of the reef system was also conducted and quantified using data from 130 sites. All parameters were higher in the reef waters adjacent to the urbanized area. pH and fecal coliform values indicated human waste contamination of the ground water at the urbanized site. Silicate and salinity values suggested that eutrophication of coastal waters was occurring at the urbanized location. The reefs at the urbanized locations were found to be much more degraded than those adjacent to the uninhabited sites.

Description of work: Field. Location: South America. Keywords: Coral, Eutrophication, Sewage, SGD, Nutrient, Salinity, Temperature, pH, Fecal Coliform

Davies, J. M., R. P. Dunne and B. E. Brown. 1997. Coral bleaching and elevated sea-water temperature in Milne Bay Province, Papua New Guinea, 1996. *Marine and Freshwater Research* **48**: 513-516.

A bleaching event occurred on reefs of Papua New Guinea in February of 1996. Bleaching was

extensive and 54% of all corals present were bleached. Branching corals, particularly *Acropora* and *Pocillopora* were more severely affected than massive species. The bleaching event was at the time of maximum monthly sea temperature and data sets recorded an anomaly of +1.29°C above normal. Analysis of temperature anomalies over the past 40 years showed a positive trend of 0.09°C per decade.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Bleaching event, Sea surface temperature, Sea water warming

Downs, C. A., J. E. Fauth, J. C. Halas, P. Dustan, J. Bemiss and C. M. Woodley. 2002. Oxidative stress and seasonal coral bleaching. *Free Radical Biology & Medicine* **33**: 533-543.

*Montastraea annularis* was studied in the Florida Keys over a single season to investigate the levels of oxidative damage products, antioxidant enzymes, and components of the cellular structure of the coral. Measurements were correlated with coral bleaching, increased sea surface temperature, and water depth. A strong positive correlation existed between accumulation of oxidative damage products and bleaching over a year of sampling. Bleaching was found to be tightly coupled to the antioxidant and stress capacity of the coral, in support of the mechanistic model that bleaching may be a strategy to defend against oxidative stress.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Bleaching, Oxidative stress, Coral reef, Oxidative damage

Downs, C. A., J. E. Fauth, C. E. Robinson, R. Curry, B. Lazendorf, J. C. Halas, J. Halas and C. M. Woodley. 2005. Cellular diagnostics and coral health: Declining coral health in the Florida Keys. *Marine Pollution Bulletin* **51**: 558-569.

The coral reef health was assessed at five sites in the Florida Keys National Marine Sanctuary and one site in Biscayne National Park in order to: document baseline changes in cellular parameters during a period of non-elevated sea surface temperature, provide a health diagnosis of corals, and determine if stresses can be attributed to local sources (run-off, boats, etc.) or climate changes. Data showed coral cover in the Marine Sanctuary declined by 38% from 1996 to 2000 and corals in Biscayne Park had been afflicted with severe oxidative damage and protein-denaturing stress, resulting in coral loss. The authors determined their method of applying a cellular diagnostic approach was helpful in identifying stress and determining coral health.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral, Reef health, Temperature, Stress, Human impact, Cellular diagnostics

Edmunds, P. J. 2005. Effect of elevated temperature on aerobic respiration of coral recruits. *Marine Biology* **146**: 655-663.

The metabolism of coral recruits was tested in response to elevated water temperatures. Measurements were taken of the diffusion boundary layer to calculate the respiration rate of coenosarc tissue on recruits of *Porites lutea* when exposed to two temperatures (26.8°C and 29.7°C) at a flow speed of 0.6 cm/s. Overall findings suggested that small corals may not be mass-transfer limited at low temperatures, but small increases in temperature may result in an

increased metabolic rate. Overall, recruits had a strong positive association with elevated temperatures which affected the metabolic consequences of water flow.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral recruits, Temperature, Respiration rate, Metabolism

Edwards, A. J., S. Clark, H. Zahir, A. Rajasurithya, A. Naseer and J. Rubens. 2001. Coral bleaching and mortality in artificial and natural reefs in Maldives in 1998, sea surface temperature anomalies and initial recovery. *Marine Pollution Bulletin* **42**: 7-15.

A bleaching event of Maldives which occurred in 1998 is examined with respect to mean sea surface temperature (SST). In a normal year, the SST usually peaks in April-May. The 1998 mean SST was 1.2-4 standard deviations above the 1950-1999 average during the warmest months. Findings showed that 98% of branching corals (*Acroporidae*, *Pocilloporidae*) died whereas the majority of massive corals (*Poritidae*, *Faviidae*, *Agariciidae*) survived. Prior to the bleaching event, the coral community consisted of 95% branching corals and 5% massives. Post-bleaching populations were 3% branching and 97% massives. Ten months after bleaching, 67% of recruits were acroporids and pocilloporids while 33% were from massive families (94% and 6% respectively, pre-bleaching years). Results showed sea surface temperatures formed a linear regression suggesting a rise of 0.16°C per decade.

Description of work: Field. Location: Indo-Pacific. Keywords: Coral, Bleaching event, Sea surface temperature, Recovery

Esslemont, G. 2000. Heavy metals in seawater, marine sediments and corals from the Townsville section, Great Barrier Reef Marine Park, Queensland. *Marine Chemistry* **71**: 215-231.

Heavy metal concentrations were measured in seawater, marine sediments and corals from the Townsville section of the Great Barrier Reef Marine Park. Seawater concentrations of all metals except lead and copper were within Australian and New Zealand Environment and Conservation Counsel (ANZECC) guidelines. Lead, copper and zinc were significantly higher in sediments than other metals. Concentrations of nickel and chromium were also higher but in relatively stable and nonreactive forms. There were higher concentrations of metals in coral tissues than in coral skeletons, although this varied by species. The authors recommend using coral skeletons rather than tissues to monitor heavy metal concentrations because they mirror environmental conditions more closely.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Heavy metal, Copper, Temperature

Fang, L.-S., S.-P. Huang and K.-L. Lin. 1997. High temperature induces the synthesis of heat-shock proteins and the elevation of intracellular calcium in the coral *Acropora grandis*. *Coral Reefs* **16**: 127-131.

The production of stress-proteins by coral cells was analyzed after heat treatment. The subcellular changes in heat-stressed corals were examined for heat-shock proteins (hsps) and calcium concentration at elevated temperatures. After heat treatment, three hsps were prominent.

The heat-shock proteins present suggested oxidative stress in coral cells during the treatment. In order to be expressed, heat-shock proteins require activation of a calcium signal. Changes in intracellular calcium concentrations were examined when under heat treatment. Calcium concentration increased at high temperatures with or without the presence of ambient calcium. This result indicated the existence of an active calcium signal in coral cells at elevated temperatures. Overall, heat treatment evokes an increase in intracellular calcium and induces the production of stress-proteins in coral cells.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral cells, Heat treatment, Temperature stress, Calcium, Heat-shock protein

Fautin, D. G. and R. W. Buddemeier. 2004. Adaptive bleaching: A general phenomenon. *Hydrobiologia* **530/531**: 459-467.

This review addresses the adaptive bleaching hypothesis (ABH) which proposes that the loss of photosymbionts has the potential to allow some representatives of the host species to re-establish a symbiosis with a different dominant alga, resulting in a new holobiont that is better suited to the altered environmental circumstances. Available laboratory and field data concerning the ABH are consistent with it so the authors generalize the ABH in light of data and observations. Overall, the authors highlight the potential importance of the ABH in the outcomes of acute bleaching.

Description of work: Review. Location: None. Keywords: Coral, Zooxanthellae, Bleaching, Adaptive bleaching hypothesis (ABH), Adaptation, Acclimation

Fitt, W. K., B. E. Brown, M. E. Warner and R. P. Dunne. 2001. Coral bleaching: interpretation of thermal tolerance limits and thermal thresholds in tropical corals. *Coral Reefs* **20**: 51-65.

This review presents a framework of thermal tolerance and thresholds for corals and how bleaching may be related to other variables that set physiological limits. Suggestions are that it is not possible to measure only one parameter of the environment and draw reliable conclusions as to stress on corals. Bleaching is a physiological process in the life of a coral; most experience stress of reduced tissue biomass and loss of algal symbionts weeks to months before the human eye can detect any signal. When bleaching occurs, corals can retain a healthy algal population. The overall concept of a bleaching threshold temperature is not a good enough explanation.

Description of work: Review. Location: None. Keywords: Coral, Bleaching, Zooxanthellae, Chlorophyll fluorescence, PAM fluorometry, Temperature threshold

Gates, R. D. 1990. Seawater temperature and sublethal coral bleaching in Jamaica. *Coral Reefs* **8**: 193-197.

Coral colonies of *Montastrea annularis*, *Porites astreoides*, *Porites porites* and *Agaricia* spp. were assessed for the presence and extent of bleaching over a period of two months at permanent study sites in Jamaica. The aim of the study was to investigate whether paling and darkening of coral coloration is a seasonal phenomenon in response to water temperature variation. The three study sites were at 6 m, 12 m, and 18 m. In 98% of the corals with bleaching, less than 25%

appeared pale. In the 2% remaining, 25% of the tissue appeared pale. The three species *M. annularis*, *P. astreoides* and *Agaricia* spp. showed a positive correlation between bleaching response and water temperature. There was no difference between percent of bleaching and water depth. Overall, *M. annularis* and *Agaricia* spp. had a higher percentage of bleached colonies than *P. astreoides* and *P. porites*.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Tissue coloration

Gleason, M. G. 1993. Effects of disturbance on coral communities: Bleaching in Moorea, French Polynesia. *Coral Reefs* **12**: 193-201.

This study was conducted during a bleaching event on reefs in Moorea, French Polynesia which began in March 1991. Significant differences existed among common coral genera in regards to degree of bleaching. *Acropora*, *Montastrea*, *Montipora*, and *Pocillopora* were more affected than *Porites*, *Pavona*, *Leptastrea* or *Millepora*. Individual colonies of *Acropora* and *Pocillopora* were further surveyed. Ninety-six percent of *Acropora* spp. showed some degree of bleaching compared to 76% of *Pocillopora* spp. Between March and August, mortality of *Pocillopora* bleached colonies was 17%, while 38% recovered completely. In contrast, 63% of the *Acropora* spp. died, and 10% completely recovered. In general, colonies with less than 50% of the colony affected recovered at a higher rate than those with more severe bleaching.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Bleaching event, Temperature, Coral recovery

Goreau, T. J., T. McClanahan, R. Hayes and A. Strong. 2000. Conservation of coral reefs after the 1998 global bleaching event. *Conservation Biology* **14**: 5-15.

Published and unpublished data is reviewed to investigate the 1998 mass bleaching event. Broad-scale implications of the event, as well as implications for coral reef conservation are discussed. Such as: the distribution and timing of Indian Ocean bleaching; bleaching in the West Pacific, East Pacific, Caribbean, and greater Atlantic; coral mortality; potential for ecosystem recovery; climate change; and conservation implications.

Description of work: Review. Location: None. Keywords: Coral Reef, Worldwide Mass Bleaching, Temperature, Conservation

Hallock, P., K. Barnes and E. Fisher. 2004. Coral reef risk assessment from satellites to molecules: a multi-scale approach to environmental monitoring and risk assessment of coral reefs. *Environmental Micropaleontology, Microbiology and Meiobenthology* **1**: 11-39.

This paper identifies some of the current threats to coral reefs: increased sediment and nutrient loads, reduced salinity, increased temperature, parasitism, bioerosion, trace elements, herbicides, pesticides, and human-synthesized chemicals. The authors suggest that current methods of coral stress detection be combined and expanded upon in order to better facilitate management and conservation efforts. Remote sensing via satellites should be used to monitor sea surface

temperatures and help predict possible coral bleachings, this technology could also be used to monitor UV and solar radiation in relation to photic stress. *In situ* monitoring of water temperature, conductivity, wind speed, turbidity, solar radiation, nutrient and chlorophyll concentrations should be conducted to distinguish natural from anthropogenic sources. This data could be used to help calibrate satellite data and establish local scales. Community structure and function should also be monitored for changes. Low cost bioindicators and micro- and meiobiota are also prospective reef monitoring tools.

Description of work: Review. Location: None. Keywords: Coral, Sediment, Heavy metal, Nutrient, Pharmaceutical, Organic, Herbicide, Pesticide, Temperature, Salinity

Harriott, V. J. 1985. Mortality rates of scleractinian corals before and during a mass bleaching event. *Marine Ecology Progress Series* **21**: 81-88.

Scleractinian coral mortality was assessed during a period of widespread bleaching at Lizard Island, Australia in 1982. Mortality was quantified during the period of bleaching and compared to data one year prior to the event. Four of the scleractinian families had mortality rates higher than the previous year. The bleaching was hypothesized to be the result of penetration of high levels of UV radiation during a time of maximum annual water temperature. Mortality rates varied among species, but were highest in smaller colonies. Overall, mortality rates showed species variation, temporal variation, and a decrease with increasing size class.

Description of work: Field. Location: Australia. Keywords: Coral, Bleaching, Temperature, Mortality, Scleractinian

Harvell, C. D., K. Kim, J. M. Burkholder, R. R. Colwell, P. R. Epstein, D. J. Grimes, E. E. Hofmann, E. K. Lipp, A. D. M. E. Osterhaus, R. M. Overstreet, J. W. Porter, G. W. Smith and G. R. Vasta. 1999. Emerging marine diseases- climate links and anthropogenic factors. *Science* **285**: 1505-1510.

This review discusses the prevalence of diseases within marine taxa in order to evaluate if a recent increase has occurred. Topics addressed include: whether an increase in disease has occurred; what conditions favor disease outbreaks; and what role do the oceans play as incubators of human diseases agents. Overall conclusions are that disease occurrence in the oceans is on the rise and more studies on marine disease need to be conducted in order to understand mechanisms of disease resistance in the marine life.

Description of work: Review. Location: None. Keywords: Coral disease, Anthropogenic factors, El Niño effects, Marine disease, Human activity, Bleaching, Coral pathogen

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld and M. D. Samuel. 2002. Climate warming and disease risks for terrestrial and marine biota. *Science* **296**: 2158-2162.

This review considers the impacts of infectious diseases and effects of climate change on marine and terrestrial biodiversity. Climate warming, from El Niño-Southern Oscillation events can

increase pathogen development and persistence, disease transmission, and host susceptibility. Topics discussed included: the current and predicted changes in climate as it relates to terrestrial and marine systems, and impacts of climate on disease for plants, wildlife, and marine life. Description of work: Review. Location: None. Keywords: Coral, Disease, Bacteria, Pathogen, Climate Change, El Niño-Southern Oscillation, Temperature

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* **50**: 839-866.

The author reviews what is known about coral bleaching and its effect on reef ecosystems. The biochemical, physiological, and ecological perspectives of coral bleaching are considered. The scientific evidence that bleaching is a sign of climate changes is discussed and builds a case for the prediction of thermally triggered bleaching events in the future. Known thermal thresholds of corals are used with the main global circulation model to predict rapid rises in sea temperature over the next 100 years if greenhouse gases continue to increase. Although reef-building corals are not likely to become extinct, their health and distribution will be severely compromised unless warming is mitigated. Topics discussed include: environmental and economic importance of the world's reefs; mass bleaching and the role of temperature; climate change and bleaching; biotic changes to changes in sea temperature; consequences of increased bleaching; and the fate of the Great Barrier Reef over the next 50 years.

Description of work: Review. Location: None. Keywords: Coral, Global climate change, Zooxanthellae, Temperature, Photoinhibition

Hoegh-Guldberg, O., M. Fine, W. Skirving, R. Johnstone, S. Dove and A. Strong. 2005. Coral bleaching following wintry weather. *Limnology and Oceanography* **50**: 265-271.

Cold stress was investigated on reefs that manifested as part of a mass bleaching event in the winter of 2003. Extensive bleaching occurred in the intertidal zone of the southern Great Barrier Reef as a result of unusually cold (minimum = 13.3°C; wet bulb temperature = 9°C) and dry winds for two days during predawn low tides. Bleached areas of affected colonies had died by September of 2003 with areas covered by 80% living coral decreasing to less than 10% visible cover. By January 2004 colonies began to recover, especially in areas unexposed during low tide. Overall, this study stressed the importance of understanding the impact that weather variability has on reefs as well as the overall shift and long term trends of global climate change.

Description of work: Field. Location: Australia. Keywords: Coral, Bleaching, Temperature, Cold stress

Hoegh-Guldberg, O. and G. J. Smith. 1989. The effect of sudden changes in temperature, light and salinity on the population density and export of zooxanthellae from the reef corals *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana. *Journal of Experimental Marine Biology and Ecology* **129**: 279-303.

This study investigated the bleaching of two pocilloporid corals, *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana, in the northern Great Barrier Reef. Both naturally and experimentally

bleached corals were used to answer these questions: (1) Is color loss due to the loss of zooxanthellae or reduced amount of photosynthetic pigment? (2) Are there different characteristics of bleaching due to light exposure as opposed to elevated temperature or reduced salinity? (3) Does the rate of zooxanthellae expulsion increase when corals are exposed to conditions that cause bleaching? Naturally bleached colonies had the same amount of chlorophyll *a* in the zooxanthellae but had reduced population densities of zooxanthellae when compared to normal colonies. In this case, bleaching was explained by low numbers of zooxanthellae and not by pale zooxanthellae. In laboratory corals, sudden exposure to full sunlight induced the bleaching of *S. pistillata*. The pale color of colonies was explained by the low pigment content of the zooxanthellae rather than low population densities. Sudden exposure to reduced salinities (30 ppt) did not affect either coral species. However, both species bleached rapidly when exposed to water temperatures above 30°C. Zooxanthellae expulsion rates remained high, even after corals were returned to control temperatures (27°C). In this case, bleached corals had reduced population densities despite normal pigment contents. Recovery of corals after temperature shock was also investigated.

Description of work: Field and Laboratory. Location: Australia. Keywords: Coral, Bleaching, Irradiance, Light, Stress, Temperature, Zooxanthellae, Salinity

Howe, S. A. and A. T. Marshall. 2002. Temperature effects on calcification rate and skeletal deposition in the temperate coral, *Plesiastrea versipora*. *Journal of Experimental Marine Biology and Ecology* **275**: 63-81.

*Plesiastrea versipora* was collected to investigate whether calcification rate changed with temperature in comparison to reef corals and if calcification was retarded in relatively cold water temperatures. The normal annual temperature range for this coral is 10-21°C which is below normal optimum for tropical corals (25-28°C). Calcification rate in field corals was maximal around 18°C, in the upper part of the normal range, similar to lab corals. Overall, both extremes of the range were detrimental to coral calcification, and field corals were more adversely affected at the lower end of the range than the higher end.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Calcification, Temperature, Acclimation, Skeletal deposition

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen and J. Roughgarden. 2003. Climate change, human impacts, and the resilience of coral reefs. *Science* **301**: 929-933.

Current knowledge of the worldwide status of coral reefs is reviewed in respect to human threats, new directions for research, and management. Projected increases in carbon dioxide levels and sea temperatures over the next 50 years exceed the conditions under which coral reefs have flourished in the past. However, reefs will not disappear entirely, but will change; with some species showing greater tolerance to bleaching than others. Topics discussed are: bleaching; acclimation and adaptation; the geological record; managing coral reef resilience; and research and management challenges.

Description of work: Review. Location: None. Keywords: Coral reefs, Climate change, Human



impact, Temperature, Carbon dioxide, Management

Iglesias-Prieto, R., J. L. Matta, W. A. Robins and R. K. Trench. 1992. Photosynthetic response to elevated temperature in the symbiotic dinoflagellate *Symbiodinium microadriaticum* in culture. Proceedings of the National Academy of Sciences **89**: 10302-10302.

This study tested the hypothesis that elevated temperature adversely affects photosynthesis in the symbiotic dinoflagellate *Symbiodinium microadriaticum* in culture. Analysis of the coral by light-mediated oxygen evolution and *in vivo* fluorescence indicated that photosynthesis was impaired at temperatures above 30°C and completely stops at 34-36°C. This suggested that the symbiotic algae were adversely affected by elevated temperatures.

Description of work: Laboratory. Location: USA. Keywords: Coral, Symbiotic algae, Zooxanthellae, Temperature, Photosynthesis

Jacques, T. G., N. Marshall and M. E. Q. Pilson. 1983. Experimental ecology of the temperate scleractinian coral *Astrangia danae*. Marine Biology **76**: 135-148.

The interactions of temperature, light and the concentration of zooxanthellae on the metabolism and calcification of *Astrangia danae* were studied. Corals were acclimated to five temperatures between 6.5°C and 27°C and incubated at three light levels and in total darkness. Respiration and photosynthesis were then measured. Calcification rates were regressed on zooxanthellae concentration and production. Respiration by the polyparium varied less within temperatures of 11.5°C and 23°C than that of the commensals (zooxanthellae), suggesting physiological acclimation by the coral tissue. *In-vivo* zooxanthellae photosynthesis increased linearly with temperature but the photosynthesis of the endolithic algae of the corallum varied little between 11.5°C and 27°C. Calcification at any temperature was near its maximum in both symbiotic and non-symbiotic corals. Calcium carbonate deposition increased linearly with temperature in non-symbiotic colonies and in symbiotic colonies incubated in the dark. In the symbiotic colonies, calcification in the light increased as temperature rose above 15°C. Below 15°C symbiotic interactions failed to stimulate calcification, due to both the lowering of zooxanthellae photosynthesis and a decrease in the level of primary production.

Description of work: Laboratory. Location: USA. Keywords: Coral, Temperature, Light, Zooxanthellae density, Calcification, Production, Respiration

Jokiel, P. L. and S. L. Coles. 1974. Effects of heated effluent on hermatypic corals at Kahe Point, Oahu. Pacific Science **28**: 1-18.

A survey of coral fauna was taken after an increase in thermal discharge due to the expansion of the Kahe Point Power Plant of the Hawaiian Electric Company in Oahu, Hawaii. The abundance of dead and damaged corals strongly correlated with proximity to plant discharge. Nearly all the corals in water 4-5°C above ambient were dead. In areas of water temperatures increased 2-4°C, there was observed loss of zooxanthellae as well as mortality. The most severe time of damage was in late summer during annual ambient temperature maxima. Overall, the result of increasing the capacity of the plant (270 to 360 megawatts) in turn increased the area of dead coral from

0.94 acres to 1.76 acres.

Description of work: Field. Location: Hawaii. Keywords: Coral, Thermal Effluent, Temperature, Mortality, Hermatypic coral

Jokiel, P. L. and S. L. Coles. 1977. Effects of temperature on the mortality and growth of Hawaiian reef corals. *Marine Biology* **43**: 201-208.

*Pocillopora damicornis*, *Montipora verrucosa*, and *Fungia scutaria* Lamark were grown in temperature-regulated continuous-flow systems. Maximum growth occurred at 26°C (natural summer ambient temperature) and was lowest at 21-22°C (natural winter ambient temperature). The temperature of 32°C caused mortality in days while long-term exposure to 30°C caused photosynthetic pigment loss, increased mortality, and decreased calcification. Life span at 18°C was 1-2 weeks. There was an initial resistance to low temperatures, but ultimately low temperatures were more harmful than high temperatures. Overall, a decrease in water temperature was more harmful than an increase of the same magnitude.

Description of work: Laboratory. Location: Hawaii. Keywords: Coral, Temperature, Zooxanthellae, Mortality, Calcification, Lethal limit

Jokiel, P. L. and S. L. Coles. 1990. Response of Hawaiian and other Indo-Pacific reef corals to elevated temperature. *Coral Reefs* **8**: 155-162.

This review addresses the critical temperatures for coral bleaching to occur. These temperatures can be expressed universally relative to the mean local summer maximum. Short-term exposure (1-2 days) at temperatures of 3-4°C above normal summer ambient or long-term exposure (several weeks) at temperatures of 1-2°C above normal summer ambient can induce bleaching. Tropical and subtropical corals live close to their lethal limits during summer months. Temperatures elevated above summer ambient but below the lethal limit can impair growth and reproduction. High light accelerates bleaching from elevated temperature. Any factor that increases respiration (high light) accelerates bleaching at high temperatures. Increased ultraviolet radiation may aggravate bleaching and mortality caused by global warming. A warming trend was observed in Hawaii where corals live close to their bleaching threshold in summer months. A continuous warming trend could lead to a mass bleaching similar to other global events.

Description of work: Review. Location: Hawaii. Keywords: Coral, Bleaching event, Temperature, Lethal limit, Summer maximum, Calcification, Photosynthesis, Respiration, Light

Kuta, K. G. and L. L. Richardson. 2002. Ecological aspects of black band disease of corals: relationships between disease incidence and environmental factors. *Coral Reefs* **21**: 393-398.

Salinity, water depth, water temperature, nitrate, nitrite, ammonium, soluble phosphate, total phosphate, turbidity, coral diversity, and percent coral cover were measured at 190 sites on 12 patch reefs. Twenty-one of the sites contained a colony with active black band disease and 169 sites contained healthy colonies susceptible to the disease. Water temperature, depth, coral

diversity, and concentrations of orthophosphate and nitrite showed statistically significant relationships with the disease.

Description of work: Field. Location: Florida. Keywords: Black band disease, Coral reef ecology, Coral reef health, Salinity, Temperature, Nutrients

Lang, J. C., H. R. Lasker, E. H. Gladfelter, P. Hallock, W. C. Jaap, F. J. Losada and R. G. Muller. 1992. Spatial and temporal variability during periods of "recovery" after mass bleaching on Western Atlantic coral reefs. *American Zoology* **32**: 696-706.

A mass bleaching event in 1987 affected coral reefs in the southwestern and central Caribbean, Florida, and the Bahamas. Monitoring of the affected corals began between December of 1987 and June of 1988 at nine affected sites. The point-count technique was used to quantify coral bleaching. Three to four months following the bleaching event, bleached corals were present in one to three of abundant coral taxa. Bleaching recovery occurred faster at shallow depths in the Bahamas and Florida sites. Scleractinian corals showed prolonged bleaching with recovery after 6-8 months following the bleaching event.

Description of work: Field. Location: Caribbean, Florida. Keywords: Coral, Bleaching event, Recovery, Zooxanthellae

Lang, J. C., R. I. Wicklund and R. F. Dill. 1988. Depth- and habitat- related bleaching of zooxanthellate reef organisms near Lee Stocking Island, Exuma Cays, Bahamas. *Proceedings of the 6th International Coral Reef Symposium* **3**: 269-274.

A major bleaching event occurred in the western Atlantic during 1987. More reef corals in 10 to 60 m depth were affected by this event compared to corals in more shallow waters near Lee Stocking Island of Exuma Sound, Bahamas. Low levels of bleaching were also observed between 65 to 91 m in January 1988. Underflows of warm saline water were detected moving from the Great Bahama Bank into the Sound during outgoing tides from 1985-1987. The authors suggest that loss of zooxanthellae from many reef organisms may have been a result of prolonged contact with the dense water masses moving through the area.

Description of work: Field. Location: Caribbean. Keywords: Coral, Temperature stress, Bleaching, Zooxanthellae, Environmental conditions

Leão, Z. M. A. N. and R. K. P. Kikuchi. 2005. A relic coral fauna threatened by global changes and human activities, Eastern Brazil. *Marine Pollution Bulletin* **51**: 599-611.

This study analyzes previous data collected of coral fauna from Holocene coral sections of two sites along the coast of Eastern Brazil. The processes responsible for the observed spatial and temporal changes in the presence of reef building coral species are discussed such as: periods of high turbidity, increasing human pressures (sedimentation, nutrification, pollution), tourism, and overfishing. The authors propose that if the current situation is paired with increases in sea surface temperature, that major reef building species in the area will soon become endangered.

Description of work: Field. Location: South American Atlantic. Keywords: Coral, Human impact, Turbidity, Sedimentation, Nutrification, Pollution, Temperature

Lesser, M. P. 1997. Oxidative stress causes coral bleaching during exposure to elevated temperatures. *Coral Reefs* **16**: 187-192.

This study examined the role of oxidative stress in the photoinhibition of cultured zooxanthellae exposed to increased temperatures by alleviating the detrimental effects of toxic oxygen. Findings supported a mechanistic role for temperature induced oxidative stress during bleaching of the Caribbean coral, *Agaricia tenuifolia*. It showed a decreased photosynthetic ability and bleaching following increased temperatures and full solar radiation. Exposure to exogenous antioxidants (scavenge reactive oxygen) improved maximum photosynthetic ability to rates no different than a coral in ambient temperature. Indications were that corals are undergoing oxidative stress and this is a mechanism for temperature-induced bleaching.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Temperature, Zooxanthellae, Photosynthetic ability, Bleaching, Oxidative stress

Lesser, M. P. and J. H. Farrell. 2004. Exposure to solar radiation increases damage to both host tissues and algal symbionts of corals during thermal stress. *Coral Reefs* **23**: 367-377.

The synergistic role of solar radiation on thermally induced stress and subsequent bleaching in *Montastraea faveolata* was examined. Under high solar radiation and elevated temperature conditions: photosystem II fluorescence in the zooxanthellae, photosynthetic pigments, and mycosporine-like amino acids (MAAs) were depressed. D1 protein concentrations were significantly lower in high light than low light under the same thermal stress. Host DNA damage was exacerbated under high light conditions. Thermal stress during exposure to high irradiance caused damage to photosystem II ability and carbon fixation in the zooxanthellae. It also caused DNA damage, apoptosis, and necrosis in the host tissue.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Bleaching, Thermal stress, Solar radiation, PSII damage, DNA damage, Apoptosis, Oxidative stress, Temperature, Irradiation

Lirman, D., B. Orlando, S. Maciá, D. Manzello, L. Kaufman, P. Biber and T. Jones. 2003. Coral communities of Biscayne Bay, Florida and adjacent offshore areas: Diversity, abundance, distribution, and environmental correlates. *Aquatic Conservation: Marine and Freshwater Ecosystems* **13**: 121-135.

The hardbottom habitat of Biscayne Bay make it a marginal environment for coral growth. An assessment of the Bay was performed to evaluate the coral populations present and investigate the factors that limit coral abundance, diversity, and distribution. Considering future changes in freshwater delivery into Biscayne Bay, due to the Everglades restoration, would affect salinity patterns and increase sediment loads which in turn are important to the abundance and distribution of corals in the area. Biscayne Bay contains a limited number of coral species. The physical characteristics of the basin make it a marginal environment for coral growth so the presence of *Siderastrea radians* and *Porites furcata* in Biscayne Bay indicate that these species are able to tolerate fluctuating conditions. Three factors, temperature, sedimentation, and salinity

appeared to limit coral abundance, diversity and distribution in the bay. Sediment burial was shown experimentally to influence growth and mortality of *S. radians*. The salinity of the bay is influenced by freshwater inputs from canal, sheetflow, and groundwater sources that create a low mean salinity near-shore environment with large salinity fluctuation. Chronic exposure to low salinity was shown experimentally to decrease the growth of *S. radians*. The location of Biscayne Bay, downstream of the Everglades watershed, highlights the need to understand the relationship between the physical environment and the benthic community health.

Description of work: Field and Laboratory. Location: Florida. Keywords: Coral community, South Florida, Salinity, Sedimentation, Temperature, Hardbottom habitat, Everglades restoration

Lough, J. M. and D. J. Barnes. 1997. Several centuries of variation in skeletal extension, density and calcification in massive *Porites* colonies from the Great Barrier Reef: A proxy for seawater temperature and a background of variability against which to identify unnatural change. *Journal of Experimental Marine Biology and Ecology* **211**: 29-67.

Calcification of *Porites* colonies was estimated by measuring skeletal density and annual extension. Annual calcification values averaged over a period between 1746-1982 was significantly related to sea surface temperature. Long-term changes in calcification of *Porites* were sensitive to temperature changes; high calcification rates occurred with high SST and vice versa. Recent declines in calcification of *Porites* may be a return to more "normal" conditions since past centuries have had much greater declines. Data collected showed that monitoring over 30-50 years must take place in order to establish what defines "normal" conditions. *Porites* may be a useful proxy for SST but may not be usefully in determining environmental degradation due to its ubiquity.

Description of work: Field. Location: Australia. Keywords: Coral, Calcification, Sea surface temperature, Porites, Density bands, Palaeoclimate

Loya, Y., K. Sakai, K. Yamazato, Y. Nakano, H. Sambali and R. v. Woesick. 2001. Coral bleaching: The winners and the losers. *Ecology Letters* **4**: 122-131.

Water temperatures at Sesoko Island, Japan peaked at an increase of 2.8°C in 1998, warmer than the 10 preceding years. This resulted in extensive coral bleaching and mortality. Random quadrat surveys were used and the coral community was documented one year before and one year after the major bleaching event. Two hypotheses were presented to explain mortality: preferential survival of thick-tissued species, and high mass transfer which facilitates survival of flat and encrusting corals over branched forms. High temperatures of 1998 reduced coral species richness by 61% and reduced coral cover by 85%. Branched corals (*Acropora* and *pocilloporid*) were the most affected while massive and encrusting corals survived. Mortality patterns produced a shift to abundance of massive and encrusting coral species over branched forms.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Bleaching, Temperature, Mortality, Global warming

Manzello, D. and D. Lirman. 2003. The photosynthetic resilience of *Porites furcata* to salinity disturbance. *Coral Reefs* **22**: 537-540.

*Porites furcata* is one of the most abundant coral species in the shallow lagoon of Biscayne Bay, Florida. Variable salinity, temperature and high sedimentation make it a marginal environment for coral growth. *P. furcata* was tested to investigate its tolerance for salinity fluctuations to occupy this environment. This species had the capacity to survive sudden salinity changes without tissue mortality, maintained autotrophy during salinity stress, acclimated to short-term salinity changes, and rapidly recovered photosynthetic rates after a return to ambient salinity. Overall, *P. furcata* survived in a marginal reef environment.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Salinity, Photosynthetic response, Temperature, Sedimentation, Coral stress

Marshall, A. T. and P. Clode. 2004. Calcification rate and the effect of temperature in a zooxanthellate and an azooxanthellate scleractinian reef coral. *Coral Reefs* **23**: 218-224.

The zooxanthellae coral *Galaxea fascicularis* and azooxanthellae coral *Dendrophyllia* sp. were used to measure calcification rates in differing water temperatures. Calcification was measured by Ca45 incorporation into corals that had been naturally acclimated to the prevailing sea temperature. Maximum calcification for both species occurred at 25°C. Calcification rates decreased rapidly at temperatures approaching the summer maximum. Both species calcified at similar rates, indicating that calcification occurs independent of light (photosynthesis).

Description of work: Laboratory. Location: Australia. Keywords: Coral, Calcification, Temperature, Zooxanthellate, Azooxanthellate

McClanahan, T. R., A. H. Baird, P. A. Marshall and M. A. Toscano. 2004. Comparing bleaching and mortality responses of hard corals between southern Kenya and the Great Barrier Reef, Australia. *Marine Pollution Bulletin* **48**: 327-335.

Bleaching and mortality response (BMI) of 19 scleractinian corals were determined during a warm-water event in 1998 in two regions, southern Kenya and eastern Australia. The response of increased water temperature on different taxa was studied. Findings showed that Kenyan corals had a greater BMI response than those in Australia. Taxa bleaching patterns were consistent between both regions. Most susceptible to bleaching were *Sylophora* and *Pocillopora* while *Cyphastrea*, *Goniopora* *Galaxea* and *Pavona* were resistant in both regions. *Acropora* and *Porites* were moderately affected in Australia but highly affected in Kenya. Overall, bleaching was phylogenetically constrained with emphasis on the features of the host's physiology or morphology. These features can be used to determine response to thermal stress.

Description of work: Field. Location: Australia and Africa. Keywords: Coral, Bleaching, Sea surface temperature, Mortality response, Scleractinian coral, Climate change, Stress

McNeil, B. I., R. J. Matear and D. J. Barnes. 2004. Coral reef calcification and climate change: The effect of ocean warming. *Geophysical Research Letters* **31**: L22309 (4 pages).

This review addresses deposition of calcium carbonate by corals, the saturation state of calcium carbonate in seawater, and sea surface temperatures (SST) as they relate to predicting future

coral reef calcification rates. The authors combine empirical relationships between coral calcification rate, calcium carbonate in seawater, and SST with output from a climate model to predict changes in coral reef calcification rates. Their analysis suggests that annual average coral reef calcification rate will increase with future ocean warming and exceed pre-industrial rates by 35% by 2100.

Description of work: Review. Location: None. Keywords: Coral reef, Calcification, Calcium carbonate, Saturation state, Temperature, Bleaching, Sea surface temperature

Miller, M. W. 1995. Growth of a temperate coral: Effects of temperature, light, depth, and heterotrophy. *Marine Ecology Progress Series* **122**: 217-225.

*Oculina arbuscula*, a temperate coral species, was used to investigate the effects of temperature and nutritional manipulations. The following questions were addressed: 1) What is the effect of winter and summer temperatures on the growth of a temperate coral in the lab and field? 2) How do light levels and fixed food supply interact to affect coral growth and chlorophyll *a* concentrations? 3) Under field conditions, how does depth affect coral growth and chlorophyll *a* concentrations? 4) Do responses to physical factors help predict coral distribution between depths in the field? Findings showed the coral had a wide temperature tolerance, but growth was higher with summer temperatures than at winter temperatures. Light and a zooplankton food sources contributed to chlorophyll *a* concentrations and additive effects on coral growth. In the field, corals grew better in shallow than in deep water. Overall, *O. arbuscula* was less abundant in habitats which it is physiologically better suited, suggesting that biotic, and not physiological factors restrict its distribution.

Description of work: Field and Laboratory. Location: USA. Keywords: Coral, Temperature, Light, Feeding, Coral growth, Environmental factors

Nakamura, T. and H. Yamasaki. 2005. Requirement of water-flow for sustainable growth of *Pocilloporid* corals during high temperature periods. *Marine Pollution Bulletin* **50**: 1115-1120.

It has been suggested that water-flow is a mitigating factor for coral bleaching. The corals *Pocillopora damicornis* and *Stylophora pistillata* were grown for 20 months to investigate this. The corals were monitored in outdoor flumes with differing flow rates (flow and still). Bleaching occurred under conditions of high sea surface temperature (SST) but both species showed shorter periods or no visible bleaching under conditions of water flow. Still water conditions resulted in growth suppression and high mortality. Overall, water-flow was concluded as an essential factor for the corals *P. damicornis* and *S. pistillata* under conditions of high SST.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Temperature, Bleaching, Water-flow, Sea surface temperature, Flow rate

Neudecker, S. 1981. Growth and survival of scleractinian corals exposed to thermal effluents at Guam. *Proceedings of the 4th International Coral Reef Symposium* **1**: 173-180.

This study measured the effect of increased temperatures from power plant effluents on the growth and survival of coral transplants of three common scleractinian species (*Porites andrewsi*, *Porites damicornis*, and *Acropora formosa*). Colonies were collected from an area that experienced periodic elevated temperatures and high turbidity. These corals were transplanted to two study sites near oil-fired generating stations; site 1 was on a fringing reef and site 2 was near an intake and outfall lagoon. Thermal enrichment was 4-6°C above ambient at both sites. Heated effluent impeded coral growth at both sites as compared to controls. *P. andrewsi* was the most tolerant of increased temperatures at both sites and had surviving colonies for the duration of the experiment (53-77 days). *P. damicornis* survived less than 30 days at site 1 and experienced less growth than controls at site 2. *A. formosa* was the most sensitive species and died within two days. Under normal conditions, the speed of growth among the three species is: *A. formosa*, *P. damicornis*, and *P. andrewsi* in decreasing order. When growth under experimental conditions was examined, the relationship was inverse to expected rates, indicating that slower growing species were more tolerant of thermal enrichment than faster growing species.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Temperature, Heated effluent, Coral growth, Scleractinian, Coral mortality

Nordemar, I., M. Nyström and R. Dizon. 2003. Effects of elevated seawater temperature and nitrate enrichment on the branching coral *Porites cylindrical* in the absence of particulate food. *Marine Biology* **142**: 669-677.

The physiological response of the coral *Porites cylindrical* was investigated when exposed to the enrichment of dissolved inorganic nitrate and high water temperature in the absence of food. The coral tolerated temperature increases without losing zooxanthellae or chlorophyll pigment, but photosynthetic ability was affected. Nitrate enrichment reduced primary production rate but did not affect zooxanthellae density and chlorophyll concentrations. Respiration rates were unaffected by the treatments. Observed reductions of tissue growth or biomass suggests a dependence on food. Overall, corals on nutrient-exposed reefs were more stressed during periods of increased temperatures compared to corals unexposed to high nutrient contents.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral, Temperature, Nutrients, Particulate food, Zooxanthellae, Respiration, Photosynthesis

Nystrom, M., I. Nordemar and M. Tedengren. 2001. Simultaneous and sequential stress from increased temperature and copper on the metabolism of the hermatypic coral *Porites cylindrical*. *Marine Biology* **138**: 1225-1231.

Stress responses from *Porites cylindrical* were measured after 24 hour exposure to copper (11  $\mu\text{g l}^{-1}$ ), increased temperature (+4°C), and a combination of these. Responses were also measured from colonies that were exposed to increased temperature for 24 hours, allowed to recover for 5 days, and then exposed to copper for 24 hours. Changes in gross primary production and respiration were measured. There was a significant reduction in primary production and respiration in response to elevated temperature and combination of elevated temperature with exposure to copper, exposure to copper alone caused a decrease in respiration but not in primary production. Corals that were exposed to increased temperature and allowed to recover for 5 days



before exposure to copper had significantly reduced primary production but no significant impact was observed on respiration. These results indicated that some stressors may affect corals in combinations more profoundly than in isolation.

Description of work: Laboratory. Location: Indo-Pacific. Keywords: Coral, Heavy metal, Copper, Temperature

Ostrander, G. K., K. M. Armstrong, E. T. Knobbe, D. Gerace and E. P. Scully. 2000. Rapid transition in the structure of a coral reef community: The effects of coral bleaching and physical disturbance. *Proceedings of the National Academy of Sciences* **97**: 5297-5302.

A 40-month study documented changes in a Caribbean reef community affected by bleaching, hurricane damage, and an abundance of macroalgae. During the study, the reef experienced a mass bleaching event resulting in a decline in coral abundance. Also, macroalgae increased until they dominated the substrate. Hurricane Lili in 1996 may have facilitated this increase in algal abundance. Results showed that a rapid phase shift from coral and algae to macroalgae dominance occurred over a short period of time.

Description of work: Field. Location: Caribbean. Keywords: Coral community, Bleaching, Storm damage, Disease, Macroalgae, Phase shift

Pitts, P. A. 2001. Hyperpycnal plumes in shelf waters of the Exuma Cays, Bahamas: A trigger for coral bleaching? *Cold Water Diving for Science* 95-100.

Increased solar radiation and high evaporation during the summer causes the waters of the Great Bahama Bank to increase in temperature and salinity. During tidal fluctuations, this water is pushed through channels between cays and onto the shelf of the Exuma Sound where most of the corals are found. It is suggested that this water is responsible for coral bleaching in the area. This study used hydrographic data collected over the shelf on the Exuma Sound to characterize the temperature, salinity, and density structure of hyperpycnal plumes after exiting the Great Bahama Bank. This was done to illustrate the behavior of the water as it is transported by currents to the shelf where it may cause coral bleaching. Findings showed that the warm hypersaline water sinks and spreads significant distances along the shelf, exposing the benthos to increases in temperature and salinity above normal conditions. Overall, the hyperpycnal bank water was a mechanism for coral bleaching.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Temperature, Salinity, Water masses

Porter, J. W., W. K. Fitt, H. J. Spero, C. S. Rogers and M. W. White. 1989. Bleaching in reef corals: Physiological and stable isotopic responses. *Proceedings of the National Academy of Sciences* **86**: 9342-9346.

Caribbean corals experienced a mass bleaching event in 1987. The authors presented physiological, stable isotopic, and population data from two species of reef-building Caribbean corals, *Montastraea annularis* and *Agaricia lamarcki*, to document their biological response. During the bleaching event, most bleached corals did not die, but energy input from

zooxanthellae decreased as determined from carbon assimilation values, *in situ* photosynthesis irradiance measurements, and tissue biomass parameters. The bleaching event was found to have coincided with abnormally elevated water temperatures.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral reef, Mass bleaching event, Temperature, Coral stress

Porter, J. W., S. K. Lewis and K. G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. *Limnology and Oceanography* **44**: 941-949.

The effects of fresh water intrusions on coral reefs were examined in the Florida Bay. The authors tested for significant effects of elevated temperature and salinity on coral production, respiration, and survival. Elevated temperatures produced reductions in photosynthesis, respiration, and net P:R ratios after 6 hours of exposure. Elevated salinities produced similar results after 30 hours. Exposure to both stressors produced a short-term mitigative interactive effect and was less stressful than the sum of the stressors acting independently for the response variables measured. After 36 hours, the mitigative effect disappeared and corals exposed to both stressors did not survive. The multiple stressors model of salinity and temperature was able to explain recent declines in coral cover within Florida Bay and the Florida Keys.

Description of work: Laboratory. Location: Florida. Keywords: Coral reef, Temperature, Salinity, Multiple coral stressors, Photosynthesis, Respiration

Potts, D. C. and P. K. Swart. 1984. Water temperature as an indicator of environmental variability on a coral reef. *Limnology and Oceanography* **29**: 504-516.

Environmental stability and habitat favorability were investigated in regards to the spatial and temporal scales experienced by corals on a reef. Shallow reef-top sites exposed to surface waters and effected by weather conditions were compared to deeper outer slope which lay well within a buffered oceanic water mass. Thermal stability (water temperature readings) and relative water movement were used as predictors of coral growth and survival. Findings showed neither thermal stability nor relative water movement was a good indicator of coral growth and survival in differing habitats. Instead, relative growth was a good index of favorability of environmental conditions.

Description of work: Field. Location: Australia. Keywords: Coral Reef, Temperature, Environmental stability

Reynaud, S., N. Leclercq, S. Romaine-Lioud, C. Ferrier-Pagès, J. Jaubert and J.-P. Gattuso. 2003. Interacting effects of CO<sub>2</sub> partial pressure and temperature on photosynthesis and calcification in a scleractinian coral. *Global Change Biology* **9**: 1660-1668.

The effects of increased pCO<sub>2</sub> and temperature on photosynthesis, respiration, and calcification were investigated in the scleractinian coral *Stylophora pistillata*. The main objectives of this study were to develop a better understanding of the effects of global environmental changes on the physiology of corals and to predict future effects. Corals were exposed to temperatures of

25°C or 28°C and to 460 or 760 microatmospheres of pCO<sub>2</sub> for five weeks. Chlorophyll *c* and protein remained constant during the experiment, while chlorophyll *a* concentrations were elevated when exposed to the high pCO<sub>2</sub>-high temperature treatment. The cell-specific density increased at high pCO<sub>2</sub> compared to normal levels. Net photosynthesis was affected by both temperature and pCO<sub>2</sub> but respiration was unaffected. Calcification decreased 50% during the high pCO<sub>2</sub>-high temperature treatment. Calcification did not change under normal pCO<sub>2</sub> and high temperature conditions. This finding disagreed with numerous papers that describe a negative relationship between calcification and CO<sub>2</sub>.

Description of work: Laboratory. Location: Mediterranean. Keywords: Coral, Calcification, Carbon Dioxide, Photosynthesis, Global change, Temperature

Riegl, B. 1995. Effects of sand deposition on scleractinian and alcyonacean corals. *Marine Biology* **121**: 517-526.

Eight scleractinia species and five alcyonacea species were collected from Natal, South Africa to test their ability to withstand sand deposition. Scleractinian were active sediment shedders while alcyonacea were passive, relying on water motion and gravity. Clearing efficiency was dependent on corallum shape. Application of sand on the corals led to hydrostatic inflation of the polyps in the scleractinia and inflation of the entire colony in alcyonacea. Inflation remained continuous during sand application while tentacular motion ceased. In both scleractinia and alcyonacea, tissue necroses occurred after one week of continuous sand application. Entire colony death and partial bleaching occurred in alcyonacea only. Grain size of the sediment had no influence on clearing reaction or efficiency.

Description of work: Laboratory. Location: Africa. Keywords: Coral, Sedimentation, Clearing efficiency, Coral mortality, Tissue bleaching

Rowan, R. 2004. Thermal adaptation in reef coral symbionts. *Nature* **430**: 742.

Some corals have adapted to increased temperatures by hosting adapted symbiotic algae (*Symbiodinium*). Two taxa of symbiotic algae (*Symbiodinium C* and *Symbiodinium D*) were tested for their tolerance to high water temperatures. The maximum quantum yield of photosystem II was measured as a ratio of variable chlorophyll fluorescence to maximum chlorophyll fluorescence ( $F_v/F_m$ ). An increase in temperature from 28.5°C to 31.3°C did not affect *Symbiodinium C* but increased  $F_v/F_m$  in *Symbiodinium D*. Exposure to a temperature of 32.0°C decreased  $F_v/F_m$  in *Symbiodinium C* whereas *Symbiodinium D* maintained an increased  $F_v/F_m$ . After temperature treatments, corals were returned to 28.5°C water. Three and four days later,  $F_v/F_m$  in *Symbiodinium C* remained lower than in controls while *Symbiodinium D*  $F_v/F_m$  ratios decreased and were similar to controls. These results suggest *Symbiodinium C* is a species sensitive to temperature and coral bleaching. Increased  $F_v/F_m$  in *Symbiodinium D* indicated photoprotection. *Symbiodinium D* was able to tolerate higher temperatures than *Symbiodinium C* algae. If other coral species are able to host symbionts of this particular taxa, they might adapt to warmer habitats.

Description of work: Laboratory. Location: Asian-Pacific. Keywords: Coral reef, Symbiotic algae, Temperature sensitivity, Photosystem II

Sakami, T. 2000. Effects of temperature, irradiance, salinity and inorganic nitrogen concentration on coral zooxanthellae in culture. *Fisheries Science* **66**: 1006-1013.

Cultured algae isolated from the hermatypic corals *Pocillopora damicornis* (strain P) and *Montipora verrucosa* (strain M) were tested to define effects of low light intensity, water temperature, salinity and inorganic nutrients. Maximum growth of strain P was observed at 32°C under all light intensities but higher photosystem 2 activity occurred at 28°C. Strain M was more affected by light intensity at all temperatures (24-36°C). Both strains had similar growth rates at low salinity (20-35 PSU) under irradiant light and moderate temperature. Overall, low irradiation and high temperature reduced tolerance against low salinity. Gross photosynthesis per cell was unaffected and cellular chlorophyll a content and cell density increased with ammonium enrichment up to 20 micromoles per day.

Description of work: Laboratory. Location: Japan. Keywords: Coral, Temperature, Salinity, Light intensity, Nutrients, Environmental stress, Zooxanthellae

Salih, A., O. Hoegh-Guldberg and G. Cox. 1997. Bleaching responses of symbiotic dinoflagellates in corals: The effects of light and elevated temperature on their morphology and physiology. Proceedings of the Australian Coral Reef Society 75th Anniversary Conference 199-216.

This study evaluated the morphological and physiological changes that occurred to dinoflagellates in the coral *Pocillopora damicornis* when subjected to elevated temperature (32°C) under shade and visible light. Chloroplast degradation occurred after 7 hours of exposure to either elevated temperature, high light intensity, or a combination of both factors. Photosynthetic efficiency was also reduced under these conditions. Overall, photosynthetically active radiation (PAR) was an important factor in bleaching and the effects of elevated temperature and high light conditions seemed to be additive. Each factor on its own had a less severe response to the coral.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Temperature, Solar radiation, Light, Morphological change, Physiological change

Schlöder, C. and L. D'Croz. 2004. Responses of massive and branching coral species to the combined effects of water temperature and nitrate enrichment. *Journal of Experimental Marine Biology and Ecology* **313**: 255-268.

Branching coral species (*Pocillopora damicornis* Linnaeus) and massive coral species (*Porites lobata* Dana) were exposed to different temperatures and nitrate concentrations for 30 days. The response of the coral-zooxanthella symbiosis was studied under the conditions of: high nutrient low temperature (upwelling), low nutrients high temperature (ENSO), and high nutrients high temperature (tropical nutrification). After experimental conditions, 30% of *P. damicornis* and 90% of *P. lobata* remained healthy. *P. damicornis* was significantly affected by nitrate addition while *P. lobata* was significantly affected by water temperature. Under high nitrate, both species exhibited increased zooxanthella volume and chlorophyll contents. High nitrate and high temperature reduced zooxanthellae density for both species. Overall, it was suggested that the slow-growing species *P. lobata* was better able to cope with changing conditions than the fast-

growing *P. damicornis*.

Description of work: Laboratory. Location: Gulf of Panama. Keywords: Coral, Temperature, Zooxanthellae, Nitrate enrichment, Sea-warming, Upwelling

Shinn, E. A., G. W. Smith, J. M. Prospero, P. Betzer, M. L. Hayes, V. H. Garrison and R. T. Barber. 2000. African dust and the demise of Caribbean coral reefs. *Geophysical Research Letters* **27**: 3029-3032.

It has been proposed that the huge transport of African dust across the Atlantic over the past 25 years has been a contributing factor to the decline of Caribbean coral reefs. Major coral bleaching events and reports of coral mortality coincide with years of maximum dust flux into the Caribbean. The elemental dust is comprised of iron, silicon, and aluminosilicate clays and also is the substrate for spores of soil fungus which has caused seafan disease in the Caribbean. The authors hypothesize that reef degradation is linked to the increase in dust transport and deposition. They propose future changes in the composition of African dust could not only affect coral reef organisms but possibly other ecosystems as well.

Description of work: Review. Location: Caribbean. Keywords: Coral, Dust, Disease, Bleaching, Mortality, Fungus, Nutrients

Smith, S. V. and R. W. Buddemeier. 1992. Global change and coral reef ecosystems. *Annual Review of Ecology and Systematics* **23**: 89-118.

This paper reviews known or probable responses of coral reef ecosystems to global change. Topics discussed include: ecosystem roles and responses; reef responses to environmental variables; pathways of climate forcing; and large-scale, local, scientific, and institutional issues. Description of work: Review. Location: None. Keywords: Coral reef systems, Global change, Carbon dioxide, Sedimentation, Sea level, Temperature, Light, Salinity, Nutrients

Stafford-Smith, M. G. 1993. Sediment-rejection efficiency of 22 species of Australian scleractinian corals. *Marine Biology* **115**: 229-243.

Interspecies variability in sediment-rejection efficiency was investigated *in-situ* for 22 Australian scleractinian coral species. Non-branching species showed a positive correlation between rejection rates and calice size. Rejection times were faster for fine grained sediment compared to coarse grained sediment at an influx of 200 mg/cm<sup>2</sup>. High water turbulence strongly influenced rejection rates of some species. Most species were able to clear sediment within 2 days. Of those that were unable to do this, *Favia stelligera* and *Leptoria phrygia* showed partial tissue death within 48 hours and *Gardineroseris planulata* did so within 6 days. Species able to tolerate sedimentation for at least 6 days exhibited extensive bleaching, but recovered after sediment removal. They included: *Montipora aequituberculata*, *Porites lobata* and *Porites lutea*. Sediment-rejection efficiency and sediment tolerance were not directly related.

Description of work: Field. Location: Australia. Keywords: Coral, Sedimentation, Water turbulence, Active-rejection, Morphology, Bleaching

Steneck, R. S. and J. C. Lang. 2003. Rapid assessment of Mexico's Yucatan reef in 1997 and 1999: Pre- and post- 1998 mass bleaching and Hurricane Mitch (stony corals, algae and fishes). *Atoll Research Bulletin* **496**: 294-317.

Assessments of reefs along Mexico's Yucatan coast were made four months following Hurricane Mitch, which affected the southern area. Coral mortality, species-specific mortality, and mortality patterns due to known stressors (bleaching, hurricanes, macroalgae) were investigated to determine changes in the reef's trophic structure. Live stony coral cover averaged <20%. High sea surface temperatures caused widespread bleaching. White-band disease prevalence among *Montastraea annularis* may have been due to bleaching occurrence. Macroalgal abundance could have resulted from anthropogenic nutrient enrichment from groundwater and/or reduced grazing.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Sea surface temperature, Hurricanes, Coral mortality, Grazing

Swarzenski, P., J. Martin and J. Cable. 2001. Submarine ground-water discharge in upper Indian River Lagoon, Florida. Water Resources Investigations Report 01-4011, USGS 1-10.

Groundwater seepage rates were measured at 28 stations along the north end of the Indian River Lagoon, FL. Lagoon and interstitial water samples were also taken. Seepage rates into the Lagoon were determined using nutrients, chloride (Cl), conductivity, pH, temperature, dissolved oxygen, and various isotope ratios. Seepage rates were found to be 3-100 ml/m<sup>2</sup>/min during the dry season and 22-144 ml/m<sup>2</sup>/min during the rainy season. Seasonal differences may indicate that there is a connection between increased rainfall and increased groundwater seepage. Measurements of Cl indicated that most (95-99%) of the interstitial water was recycled lagoon water and did not originate from groundwater seepage. Nutrient concentrations were found to be 3-5 times higher in the seepage water over the lagoon, indicating that submarine groundwater discharge is important to the coastal nutrient budget.

Description of work: Field. Location: Indian River Lagoon, FL. Keywords: SGD, nutrients, salinity, temperature, pH

Szmant, A. M. and N. J. Gassman. 1990. The effects of prolonged "bleaching" on the tissue biomass and reproduction of the reef coral *Montastrea annularis*. *Coral Reefs* **8**: 217-224.

Florida coral colonies of *Montastrea annularis* were studied to determine the long term effects of bleaching on coral physiology resulting from a Caribbean bleaching event. Nine colonies were sampled to determine whether loss of zooxanthellae has an effect on coral biomass and sexually reproduction. There were two types of colonies found: low numbers of zooxanthellae with normal pigment content, and high densities of zooxanthellae with low pigment content. Findings were that bleached corals were unable to complete gametogenesis while recovered corals were able to complete a normal cycle. Bleached corals were able to survive without nutrition from zooxanthellae for a prolonged period of time by using structural materials for maintenance, but were unable to reproduce. Recovered corals which regained zooxanthellae after bleaching were

able to reproduce and did not suffer loss of tissue biomass.

Description of work: Field. Location: Florida. Keywords: Coral, Bleaching, Tissue biomass, Reproduction, Zooxanthellae

Warner, M. E., W. K. Fitt and G. W. Schmidt. 1996. The effects of elevated temperature on the photosynthetic efficiency of zooxanthellae *in hospite* from four different species of reef coral: a novel approach. *Plant, Cell and Environment* **19**: 291-299.

The goal of this study was to investigate the physiological effects of increased temperature on zooxanthellae living in different hosts from different habitats. This was done to gain insight into why some organisms bleach while others do not. Using PAM fluorometry and DCMU whole-cell fluorescence of isolated zooxanthellae within the corals *Montastrea annularis*, *Agaricia lamarki*, *Agaricia agaricites* and *Siderastrea radians*, the authors attempted to identify different mechanisms by which photosynthetic efficiency of the algae are reduced during exposure to elevated temperatures. Zooxanthellae in *M. annularis* and *A. lamarki* were the most sensitive to elevated temperature as compared to the other species, with complete photosynthesis disruption occurring between 32-34°C. Fundamental differences were found in the physiology of the symbionts in the different species of coral. Zooxanthellae in *M. annularis* were more susceptible to heat-induced damage near the reaction center of Photosystem II, while zooxanthellae in *S. radians* remained capable of dissipating excess energy through non-photochemical pathways, thereby protecting the photosystem from damage during the heat exposure.

Description of work: Laboratory. Location: Caribbean. Keywords: Coral, Bleaching, Zooxanthellae, Chlorophyll fluorescence, PAM fluorometry, Photoinhibition, Temperature stress

Wilkinson, C. R. 1999. Global and local threats to coral reef functioning and existence: review and predictions. *Marine and Freshwater Research* **50**: 867-878.

This review attempts to predict the consequences of direct and indirect anthropogenic factors affecting coral reefs as the human population and economic activity increase. The focus is on the past 10 years of research papers and reviews. Topics discussed include the effects of: latitude, depth, temperature, salinity, nutrient levels, geological disturbances, storms and other climactic disturbances, freshwater inundation, low tide exposure, predator and disease outbreak, increased sediment loads, organic and inorganic pollution, complex organic and heavy metal pollutants, over-exploitation, oil and petroleum products, engineering and military damage, increased carbon dioxide concentrations, increased UVB radiation, changes in sea level, and weather. The short-term prediction includes reductions in the extent and biodiversity of coral reefs with disruption to cultures and economies dependent on them. The long-term prediction is more encouraging in that coral reefs are resilient and may stabilize as changes to the environment stabilize.

Description of work: Review. Location: None. Keywords: Coral, Anthropogenic factors, Stress, Sedimentation, Pollution, Bleaching, Mortality, Calcification, Carbon Dioxide, Sea Level

Winter, A., R. S. Appeldoorn, A. Bruckner, E. H. W. Jr. and C. Goenaga. 1998. Sea surface temperatures and coral reef bleaching off La Parguera, Puerto Rico (northeastern

Caribbean Sea). *Coral Reefs* **17**: 377-382.

Bleaching at a Caribbean reef was compared to a thirty-year record of sea surface temperature (SST). Seven annual temperature indices were devised to determine the predictability of coral bleaching episodes. Three of these indices (maximum daily temp, >29.5°C, and >30°C) correctly predict four years with severe bleaching. A log-log linear relationship is found between SST and number of days above the SST which bleaching occurred. The relationship between bleaching and temperature indicated no one predictor can result in bleaching within a year.

Description of work: Field. Location: Caribbean. Keywords: Coral, Bleaching, Sea surface temperature

Yap, H. T. 2004. Differential survival of coral transplants on various substrates under elevated water temperatures. *Marine Pollution Bulletin* **49**: 306-312.

This study compared the survival of coral transplants when attached to different substrates. Live colonies of *Porites cylindrica*, dead colonies of *P. cylindrica*, and epoxy coated metal grids that were raised above the substrate were the three substrates used. The two species studied were *Porites cylindrica* and *Porites rus*. The two related species were compared in terms of their responses to elevated water temperatures and subsequent survival on different substrates. Transplants of each species were attached to each substrate type with an onset of above-normal water temperatures due to the El Niño episode of 1998. Findings were *P. cylindrica* showed signs of bleaching followed by algal overgrowth and mortality. *P. rus* bleached more slowly and had less mortality with some signs of recovery after 14 weeks of observation. Survival of transplanted corals was the higher on the metal grids (avg 35%), then compared to the live coral (avg 22%). Dead coral had the lowest rate of survival (avg 6%). Overall, metal grids and live coral substrate provide a favorable environment for attached coral fragments to persist, regardless of species. Attachment of live coral onto dead colonies for the purpose of increasing live coral cover did not yield favorable results.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Temperature, Coral transplant, Substrate, Bleaching

### **Turbidity**

Anthony, K. R. N. 1999. A tank system for studying benthic aquatic organisms at predictable levels of turbidity and sedimentation: Case study examining coral growth. *Limnology and Oceanography* **44**: 1415-1422.

This study tests a flow-through tank system that allows exposure of benthic organisms to predictable concentrations of suspended particulate matter (SPM) and differing rates of sedimentation. The growth rates of *Goniastrea retiformis* and *Porites cylindrica* were monitored over an 8-week period. The effect of shading was also tested by using two light levels at low and high particle concentrations. The growth rate of *G. retiformis* increased as a function of SPM concentration (1-16 mg/L) while *P. cylindrica* was unaffected by particle load. Both species had reductions in growth under conditions of shade and 16 mg/L SPM concentration. The author



hypothesized that the two species had different abilities to utilize SPM as a food source or different susceptibilities to SPM as a stress factor.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Sedimentation, Turbidity, Light, Shading, Suspended particulate matter (SPM)

Anthony, K. R. N. 2000. Enhanced particle-feeding capacity of corals on turbid reefs (Great Barrier Reef, Australia). *Coral Reefs* **19**: 59-67.

This study tested the hypothesis that corals from turbid inshore reefs in the Great Barrier Reef (GBR) lagoon have developed a greater capacity to feed on suspended sediment compared to species from less turbid nearshore and midshelf reefs. Two species common to the area, *Pocillopora damicornis* and *Acropora millepora*, were used for the experiment. The particle clearing rates of corals from turbid reefs were two-four times greater than those from less turbid and midshelf reefs. Sediment ingestion was a linear function of sediment load. Estimated carbon-14 assimilation varied between 50 and 80% and was maximized for midshelf *A. millepora*, indicating that heterotrophy is more efficient in oligotrophic habitats. Overall, coral species on turbid inshore reefs were 10-20 times more heterotrophic on suspended sediment than the same species on less turbid and midshelf reefs.

Description of work: Laboratory. Location: Australia. Keywords: Coral reef, Turbidity, Sedimentation, Particle clearing rate, Suspended sediment, Particle feeding

Anthony, K. R. N. and K. E. Fabricius. 2000. Shifting roles of heterotrophy and autotrophy in coral energetics under varying turbidity. *Journal of Experimental Marine Biology and Ecology* **252**: 221-253.

Feeding rates on natural suspended particulate matter (SPM) can allow scleractinian corals to compensate for reduced phototrophy in turbid environments by using the SPM as a food source. Two corals were tested with differing phototrophic-heterotrophic capacities (*Goniastrea retiformis* and *Porites cylindrical*) and showed stress and growth optima at differing combinations of light and SPM amounts. Due to its phototrophic and heterotrophic plasticity, *G. retiformis* gained tissue and skeletal mass at all experimental levels of light and SPM. Due to lack of plasticity, *P. cylindrical* showed energy deficiency during high turbidity and these conditions appeared physiologically unsustainable for this species. Overall, plasticity offset stress from high particle loads.

Description of work: Laboratory. Location: Australia. Keywords: Coral, Turbidity, Heterotrophy, Autotrophy, Trophic plasticity, Sediment, Scleractinian coral

Dodge, R. E., R. C. Aller and J. Thomson. 1974. Coral growth related to resuspension of bottom sediments. *Nature* **247**: 574-577.

The effects of resuspension of bottom sediments on the growth rate of *Montastrea annularis* in Discovery Bay, Jamaica was investigated. Growth rate of the coral was determined using a <sup>228</sup>Ra technique and X radiography. There was found to be an inverse relationship between resuspension and coral growth; as resuspension increased, growth decreased going from east to

west. The standard deviation of maximum and average growth decreased as resuspension increased. This indicated that high resuspension hinders coral growth as well as variability in growth. The ability of the coral to respond to less-limiting environmental conditions was therefore reduced by high resuspension rates.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Turbidity, Resuspension, Growth rate

Fabricius, K. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

This review focused on the direct effects of terrestrial runoff on coral reef communities at regional scales. The author identified inorganic nutrients and particulate matter as the most important contaminants of coral reefs on national and regional levels. Available data on the response of coral reef organisms to the following stressors was evaluated: increased dissolved inorganic nutrients; increased concentrations of particulate organic matter; light reduction; and increased sedimentation. The effects of these four stressors on hard coral colony calcification, tissue growth, symbiosis, reproduction and recruitment were evaluated. The author also looked at some other organisms that affected the abundance of hard corals, and their responses to the above stressors. These included bioeroders, macroalgae, filter feeders, octocorals, disease pathogens and predators. The author concluded that dissolved inorganic nutrients can reduce coral calcification rates, reduce fertilization success, and may promote species of macroalgae that compete for space with corals. Particulate organic matter and turbidity related light limitations have the same effect on heterotrophic filter feeders. Light limitation also reduces coral recruitment. Sedimentation also reduced growth and survival of corals, especially in recruitment and early life stages.

Description of work: Review. Location: None. Keywords: Nutrient, Sediment, Turbidity, Coral

Fabricius, K. and M. Dommissie. 2000. Depletion of suspended particulate matter over coastal reef communities dominated by zooxanthellate soft corals. *Marine Ecology Progress Series* **196**: 157-167.

The authors investigated the *in situ* rates of net depletion of natural suspended particulate matter (SPM) by reefs dominated by zooxanthellate alcyoniid soft corals. Concentrations of SPM in water parcels were measured before and after passing over 2 soft coral dominated reef strips and 2 sand-dominated strips. Downstream of the reef there was a depletion of chlorophyll, particulate organic carbon, and particulate phosphorus. The standing stock averaged 35% chlorophyll depletion while net depletion for particulate organic carbon and particulate phosphorus were 15 and 23% respectively. Concentrations of particulate nitrogen and phaeopigments were similar before and after passage across the reef sites. On the sandy sites, downstream concentrations of particulate nitrogen, chlorophyll, and phaeopigments were similar to upstream concentrations. The net import of particulate organic carbon into the reef was estimated to be  $\sim 2.5 \text{ g C/m}^2/\text{d}$ . Less than 20% of this import could be explained by removal sponges, tunicates, bivalves, and hard corals, suggesting that soft corals were the primary sinks of carbon. Overall, it is suggested that detritus and other small SPM are an important food

sources for alcyoniid-dominated reef communities that experience high levels of turbidity. Description of work: Field and Laboratory. Location: Australia. Keywords: Coral reef community, Turbidity, Suspended particulate matter (SPM), Particulate organic matter (POM), Suspension feeding

Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. *Marine Pollution Bulletin* **50**: 125-146.

A review of current knowledge on the direct effects of terrestrial runoff, namely: the growth and survival of hard corals, coral reproduction and recruitment, and organisms that interact with coral communities are investigated. Response of each of these is evaluated against water quality parameters: increased dissolved inorganic nutrients, enrichment of organic matter, light reduction from turbidity, and increased sedimentation. Conclusions are that dissolved inorganic nutrients reduce coral calcification and fertilization rates and increase macroalgal abundance. Also, enrichment of particulate organic material enhances feeding rates and growth in some corals giving an advantage to compensate for light reduction (especially in high-flow settings). Lastly, turbidity light limitation reduces gross photosynthesis and reduces coral recruitment, and sedimentation reduces growth and survival of coral depending on species and sediment type. Description of work: Review. Location: None. Keywords: Coral, Sedimentation, Nutrients, Turbidity, Coral reproduction, Recruitment, Light

Kim, K., P. D. Kim, A. P. Alker and C. D. Harvell. 2000. Chemical resistance of gorgonian corals against fungal infections. *Marine Biology* **137**: 393-401.

*Aspergillus sydowii*, a disease caused by a fungal pathogen, was studied. Corals were experimentally evaluated to investigate natural mechanisms of disease resistance. Antifungal compounds were effective in disease prevention when found in high concentrations and high potency. A specificity of *Aspergillus sydowii* for *Gorgonia ventalina* and *G. flabellum* may indicate a heightened sensitivity to changes in water quality which can compromise disease resistance. The impact of this pathogen was higher on reefs with high nutrient levels and turbidity which indicated water quality as an important factor in host-pathogen interactions. Description of work: Laboratory. Location: Florida. Keywords: Coral disease, *Aspergillus sydowii*, Coral pathogen, Disease resistance, Nutrients, Turbidity, Water Quality

Larcombe, P. and K. J. Woolfe. 1999. Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. *Coral Reefs* **18**: 163-169.

Sediment supply over the past 200 years has increased due to human impact on the catchments in Australia. The Great Barrier Reef is under threat from increases in turbidity and sedimentation. By using geological data and information on sedimentary processes, this review postulates that turbidity levels and sediment accumulation at most reef areas will not increase as a result of these factors not being limited by sediment supply.

Description of work: Review. Location: Australia. Keywords: Coral reefs, Human impacts, Sedimentation, Turbidity

Leão, Z. M. A. N. and R. K. P. Kikuchi. 2005. A relic coral fauna threatened by global changes and human activities, Eastern Brazil. *Marine Pollution Bulletin* **51**: 599-611.

This study analyzes previous data collected of coral fauna from Holocene coral sections of two sites along the coast of Eastern Brazil. The processes responsible for the observed spatial and temporal changes in the presence of reef building coral species are discussed such as: periods of high turbidity, increasing human pressures (sedimentation, nutrification, pollution), tourism, and overfishing. The authors propose that if the current situation is paired with increases in sea surface temperature, that major reef building species in the area will soon become endangered. Description of work: Field. Location: South American Atlantic. Keywords: Coral, Human impact, Turbidity, Sedimentation, Nutrification, Pollution, Temperature

Loya, Y. 1976. Effects of water turbidity and sedimentation on the community structure of Puerto Rican corals. *Bulletin of Marine Science* **26**: 450-466.

This study correlated turbidity and sedimentation data obtained by other investigators to the coral community structure and species diversity of corals off the west coast of Puerto Rico. The area of study is heavily stressed by sediments from two rivers that discharge into the area. The East Reef on a steep slope (11-17-m depth) was compared to the flat West Reef (20-m depth). Coral diversity and coral cover were high at the East Reef while averages for turbidity and sedimentation were low. In contrast, coral diversity and coral cover at the West Reef were low while the average turbidity and sedimentation levels were high. On both reefs, the species with the greatest efficiency of sediment rejection was *Montastrea cavernosa*. Other species on the West Reef that succeeded under the high turbidity and sedimentation conditions were: *Siderastrea radians*, *Siderastrea siderea*, *Diploria strigosa*, and *Meandrina meandrites*. Overall findings suggest that differences in the community structure between the East Reef and West Reef are the result of turbidity and sedimentation levels.

Description of work: Field. Location: Caribbean. Keywords: Coral, Sedimentation, Turbidity, Coral stress, Diversity, Community structure

Orpin, A. R., P. V. Ridd, S. Thomas, K. R. N. Anthony, P. Marshall and J. Oliver. 2004. Natural turbidity variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. *Marine Pollution Bulletin* **49**: 602-612.

This study characterized the natural turbidity regime of an inshore fringing reef in the central Great Barrier Reef. A risk management scheme was outlined to minimize construction-related increases in turbidity. Comparisons between control and impact sites proved unusable for real-time management of turbidity risks. The authors suggested using a one standard deviation range from ambient conditions as a conservative upper limit of an acceptable increase in turbidity. Also, regional weather forecast is suggested for use in turbidity assessment, however this approach is limited in rough conditions when anthropogenic turbidity increases could be fatal to corals already stressed under natural conditions.

Description of work: Field. Location: Australia. Keywords: Coral reef, Turbidity, Sediment,

Impact management, Coastal development, Coral stress, Weather impacts

Telesnicki, G. J. and W. M. Goldberg. 1995. Effects of turbidity on the photosynthesis and respiration of two South Florida reef coral species. *Bulletin of Marine Science* **57**: 527-539.

Two scleractinian coral species from Florida, *Dichocoenia stokesii* and *Meandrina meandrites*, were studied in vitro under turbid conditions. Photosynthetic and respiratory responses were measured at differing levels of turbidity; 7-9, 14-16, and 28-30 Nephelometric Turbidity Units (NTU) and compared to controls at 0-2 NTU. No difference was found between the control and 7-9 NTU groups. Both species exhibited changes in P:R ratios after 2-3 days in the 14-16 and 28-30 NTU groups when compared to controls. High levels of turbidity increased mucus production for both species. Turbidity-related changes in the P:R ratios were a result of increased respiration and not decreased photosynthesis. Overall results suggest turbidity in Florida waters may result in short term stress and long term decline of corals.

Description of work: Laboratory. Location: Florida. Keywords: Coral, Turbidity, Photosynthesis, Respiration, Light, P:R, Coral stress

Thomas, S., P. V. Ridd and G. Day. 2003. Turbidity regimes over fringing coral reefs near a mining site at Lihir Island, Papua New Guinea. *Marine Pollution Bulletin* **46**: 1006-1014.

A sediment transport survey was taken where mining operations involve disposal of waste rocks and soil into nearby water. Potential impacts of this practice were investigated to determine potential impacts on fringing reefs. Turbidity and sediment accumulation were measured over a period of 18 months. Measurements indicated that an extreme turbidity gradient persists and that observed zones conform with pre-operations impact predictions. Accumulation measurements indicated no significant smothering or burial to any fringing reefs.

Description of work: Field. Location: Asian-Pacific. Keywords: Coral, Sediment, Turbidity, Mining impact, Fringing coral reef

Wolanski, E., R. H. Richmond and L. McCook. 2004. A model of the effects of land-based, human activities on the health of coral reefs in the Great Barrier Reef and in the Fouha Bay, Guam, Micronesia. *Journal of Marine Systems* **46**: 133-144.

Historical data on natural disturbances, oceanographic conditions, and the natural evolution of reefs was gathered to extract parameters for a model. The model explains human-induced changes in quality and quantity of terrestrial runoff and reef degradation (phase-shifts) on two sites: the Great Barrier Reef, Australia and Fouha Bay, Guam. It successfully reproduced the observed distribution of algae and coral for both sites. Conclusions were that reef degradation is due to human activities and recovery is possible if remedial measures are implemented on land to restore water and substrate quality.

Description of work: Field. Location: Australia and Asian-Pacific. Keywords: Coral reef, Model, Phase shift, Runoff, Turbidity, Algae, Environmental degradation, Management

