October 2010

Marine Science Review – 394

Coral and coral reefs

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In this review:

O / A **denotes an open access article or journal**

A. Recent articles – no abstract

Tsounis, G., Rossi, S., Grigg, R., Santangelo, G., Bramanti, L., and Gili, J.M. The exploitation and conservation of precious corals. *Oceanography and Marine Biology: An Annual Review* 48: 161-212, 2010.

Samimi Namin, K., Risk, M.J., Hoeksema, B.W., Zohari, Z., and Rezai, H. Coral mortality and serpulid infestations associated with red tide, in the Persian Gulf. *Coral Reefs* 29(2): 509, 2010.

Scharer, M.T. and Nemeth, M.I. Mass mortality of gorgonians due to a *Cyphoma gibbosum* (Linnaeus) population outbreak at Mona Island, Puerto Rico. *Coral Reefs* 29(2): 533, 2010.

B. Recent articles with abstracts

Costantini, F., Taviani, M., Remia, A., Pintus, E., Schembri, P.J., and Abbiati, M. Deep-water *Corallium rubrum* (L., 1758) from the Mediterranean Sea: preliminary genetic characterisation. *Marine Ecology* 31(2): 261-269, 2010.

Notes: The precious red coral *Corallium rubrum* (L., 1758) lives in the Mediterranean Sea and adjacent Eastern Atlantic Ocean on subtidal hard substrates. *Corallium rubrum* is a long-lived gorgonian coral that has been commercially harvested since ancient times for its red axial calcitic skeleton and which, at present, is thought to be in decline because of overexploitation. The depth distribution of *C. rubrum* is known to range from c. 15 to 300m. Recently, live red coral colonies have been observed in the Strait of Sicily at depths of c. 600-800m. This record sheds new light on the ecology, biology, biogeography and dispersal mechanism of this species and calls for an evaluation of the genetic divergence occurring among highly fragmented populations. A genetic characterization of the deep-sea red coral colonies has been done to investigate biological processes affecting dispersal and population resilience, as well as to define the level of isolation / differentiation between shallow- and deep-water populations of the Mediterranean Sea. Deep-water *C. rubrum* colonies were collected at two sites (south of Malta and off Linosa Island) during the cruise MARCOS of the R / V Urania. Collected colonies were genotyped using a set of molecular markers differing in their level of polymorphism. Microsatellites have been confirmed to be useful markers for individual genotyping of *C. rubrum* colonies. ITS-1 and mtMSH sequences of deep-water red coral colonies were found to be different from those found in shallow water colonies, suggesting the possible occurrence of genetic isolation among shallow- and deep-water populations. These findings suggest that genetic diversity of red coral over its actual range of depth distribution is shaped by complex interactions among geological, historical, biological and ecological processes.

Nijman, V. An overview of international wildlife trade from Southeast Asia. *Biodiversity and Conservation* 19(4): 1101-1114, 2010.

Notes: Wildlife trade is the very heart of biodiversity conservation and sustainable development providing an income for some of the least economically affluent people and it generates considerable revenue nationally. In Asia the unsustainable trade in wildlife has been identified as one of the main conservation challenges. Internationally, wildlife trade is regulated through the Convention on International Trade in Endangered Species of wild fauna and flora (CITES) to which all Southeast Asian nations are signatory. I obtained data on international trade in CITES-listed animals in the period 1998-2007. In all >35 million animals (0.3 million butterflies; 16.0 million seahorses; 0.1 million other fish; 17.4 million reptiles; 0.4 million mammals; 1.0 million birds) were exported in this period, 30 million (~300 species) of them being wild-caught. In addition 18 million pieces and 2 million kg of live corals were exported. Malaysia, Vietnam, Indonesia and China are the major exporters of wild-caught animals and the European Union and Japan are the most significant importers. Over this period exports in birds significantly decreased, trade in the other taxa either increased or remained stable. For all taxa but butterflies the vast majority of individuals represent wild-caught individuals. Records of illegal or undeclared international trade are scant but can be significantly larger than levels of official exports. It is concluded that there is an urgent need for better assessments of what levels of exploitation are sustainable (including exploring appropriate proxies for Non Detriment Findings), for initiatives to make regulatory mechanisms more effective (including the introduction of minimum mandatory standards and monitoring selected wildlife trade hubs), and for better licensing and registration. Funding for at least some of these initiatives can be obtained by imposing small levies on exports of CITES-listed wildlife.

Richards, Z.T., Wallace, C.C., and Miller, D.J. Archetypal 'elkhorn' coral discovered in the Pacific Ocean. *Systematics and Biodiversity* 8(2): 281-288, 2010.

Notes: The discovery of a population of elkhorn corals in the Central Pacific Ocean has important taxonomic implications, as this distinctive colony morphology was previously known only from the endemic and critically endangered Atlantic species *Acropora palmata*. Phylogenetic analyses confirmed that the Pacific elkhorn coral is genetically distant from *A. palmata*, and most likely represents a species previously synonymized with *Acropora abrotanoides*. The Pacific elkhorn coral is rare, and is of particular scientific interest because it represents one morphological extreme in the dominant genus of reef-building corals. The discovery of the Pacific elkhorn coral raises a number of important general issues in relation to biodiversity conservation, as this coral would not qualify for threatened species listing under current IUCN categories and criteria despite being demonstrably rare.

Ainsworth, T.D., Thurber, R.V., and Gates, R.D. The future of coral reefs: a microbial perspective. *Trends in Ecology and Evolution* 25(4): 233-240, 2010.

Notes: Microbial communities respond and quickly adapt to disturbance and have central roles in ecosystem function. Yet, the many roles of coral-associated microbial communities are not currently accounted for in predicting future responses of reef ecosystems. Here, we propose that a clearer understanding of coral-associated microbial diversity and its interaction with both host and environment will identify important linkages occurring between the microbial communities and macroecological change. Characterizing these links is fundamental to understanding coral reef resilience and will improve our capacity to predict ecological change.

Reed, K.C., Muller, E.M., and van Woesik, R. Coral immunology and resistance to disease. *Diseases of Aquatic Organisms* 90(2): 85-92, 2010.

Notes: Scleractinian corals (phylum Cnidaria, class Anthozoa) have innate immunological responses against infections. Research has recently suggested that corals also possess an adaptive-like immunological repertoire that recognizes specific pathogens and allografts. While evolutionarily distinct, the corals' innate and adaptive-like immunity systems are not mutually exclusive because the phagocytic cells of the non-specific, innate immune system may activate specific adaptive immunological responses. Warming oceans may immunocompromise coral hosts, making them more susceptible to tropical marine diseases,

independent of the virulence of the pathogen. The ability of corals to ward off both primary and opportunistic infections, through adaptive-like mechanisms, may play a critical role in the corals' ability to fight future disease infection. Here we show evidence that corals possess immunological repertoires that extend well beyond simple innate defenses. The extent to which corals have developed such an adaptive-like immune repertoire will determine whether corals will survive climate change and other anthropogenic disturbances.

Selig, E.R., Casey, K.S., and Bruno, J.F. New insights into global patterns of ocean temperature anomalies: implications for coral reef health and management. *Global Ecology and Biogeography* 19(3): 397-411, 2010.

Notes: *Aim* Coral reefs are widely considered to be particularly vulnerable to changes in ocean temperatures, yet we understand little about the broad-scale spatio-temporal patterns that may cause coral mortality from bleaching and disease. Our study aimed to characterize these ocean temperature patterns at biologically relevant scales. *Location* Global, with a focus on coral reefs. *Methods* We created a 4-km resolution, 21-year global ocean temperature anomaly (deviations from long-term means) database to quantify the spatial and temporal characteristics of temperature anomalies related to both coral bleaching and disease. Then we tested how patterns varied in several key metrics of disturbance severity, including anomaly frequency, magnitude, duration and size. *Results* Our analyses found both global variation in temperature anomalies and fine-grained spatial variability in the frequency, duration and magnitude of temperature anomalies. However, we discovered that even during major climatic events with strong spatial signatures, like the El Nino-Southern Oscillation, areas that had high numbers of anomalies varied between years. In addition, we found that 48% of bleaching-related anomalies and 44% of disease-related anomalies were less than 50 km^2, much smaller than the resolution of most models used to forecast climate changes. *Main conclusions* The fine-scale variability in temperature anomalies has several key implications for understanding spatial patterns in coral bleaching- and disease-related anomalies as well as for designing protected areas to conserve coral reefs in a changing climate. Spatial heterogeneity in temperature anomalies suggests that certain reefs could be targeted for protection because they exhibit differences in thermal stress. However, temporal variability in anomalies could complicate efforts to protect reefs, because high anomalies in one year are not necessarily predictive of future patterns of stress. Together, our results suggest that temperature anomalies related to coral bleaching and disease are likely to be highly heterogeneous and could produce more localized impacts of climate change.

Choi, H., Engene, N., Smith, J.E., Preskitt, L.B., and Gerwick, W.H. Crossbyanols A-D, toxic brominated polyphenyl ethers from the Hawai'ian bloom-forming cyanobacterium *Leptolyngbya crossbyana*. *Journal of Natural Products* 73(4): 517-522, 2010.

Notes: Periodically, the marine cyanobacterium *Leptolyngbya crossbyana* forms extensive blooms on Hawai'ian coral reefs and results in significant damage to the subtending corals. Additionally, corals near mats of this cyanobacterium, but not directly overgrown, have been observed to undergo bleaching. Therefore, samples of this cyanobacterium were chemically investigated for bioactive secondary metabolites that might underlie this toxicity phenomenon. H-1 NMR spectroscopy-guided fractionation led to the isolation of four heptabrominated polyphenolic ethers, crossbyanols A – D (1 – 4). Structure elucidation of these compounds was made challenging by their very low proton to carbon (H/C) ratio, but was completed by combining standard NMR and MS data with 2 Hz-optimized HMBC data. Derivatization of crossbyanol A as the diacetate assisted in the assignment of its structure. Crossbyanol B (2) showed antibiotic activity with an MIC value of 2.0-3.9 μg/mL against methicillin-resistant *Staphylococcus aureus* (MRSA) and relatively potent brine shrimp toxicity (IC_{50} 2.8 ppm).

Houk, P. and Raubani, J. *Acanthaster planci* outbreaks in Vanuatu coincide with ocean productivity, furthering trends throughout the Pacific Ocean. *Journal of Oceanography* 66(3): 435-438, 2010.

Notes: This study identifies linkages between regional ocean productivity and the emergence of large *Acanthaster planci* starfish populations in Vanuatu. Positive correlations were found between wind stress, chlorophyll-*a*, and upwelling during January February 2009, corresponding with coral-eating starfish occurrences. Further, temporal associations have existed between monthly wind stress and upwelling since 2000, and were predictors of past starfish events. Links between starfish emergence

and oceanographic features are discussed, drawing upon evidence from other asteroid echinoderms. High regional productivity associated with anomalous oceanographic conditions in Vanuatu, and globally, can be used as early warning indicators of probable, future starfish emergence to aid the foundation and success of local management efforts.

Jury, C.P., Whitehead, R.F., and Szmant, A.M. Effects of variations in carbonate chemistry on the calcification rates of *Madracis auretenra* (= *Madracis mirabilis sensu* Wells, 1973): bicarbonate concentrations best predict calcification rates. *Global Change Biology* 16(5): 1632-1644, 2010.

Notes: Physiological data and models of coral calcification indicate that corals utilize a combination of seawater bicarbonate and (mainly) respiratory CO_2 for calcification, not seawater carbonate. However, a number of investigators are attributing observed negative effects of experimental seawater acidification by CO_2 or hydrochloric acid additions to a reduction in seawater carbonate ion concentration and thus aragonite saturation state. Thus, there is a discrepancy between the physiological and geochemical views of coral biomineralization. Furthermore, not all calcifying organisms respond negatively to decreased pH or saturation state. Together, these discrepancies suggest that other physiological mechanisms, such as a direct effect of reduced pH on calcium or bicarbonate ion transport and/or variable ability to regulate internal pH, are responsible for the variability in reported experimental effects of acidification on calcification. To distinguish the effects of pH, carbonate concentration and bicarbonate concentration on coral calcification, incubations were performed with the coral *Madracis auretenra* (= *Madracis mirabilis sensu* Wells, 1973) in modified seawater chemistries. Carbonate parameters were manipulated to isolate the effects of each parameter more effectively than in previous studies, with a total of six different chemistries. Among treatment differences were highly significant. The corals responded strongly to variation in bicarbonate concentration, but not consistently to carbonate concentration, aragonite saturation state or pH. Corals calcified at normal or elevated rates under low pH (7.6-7.8) when the seawater bicarbonate concentrations were above 1800 µm. Conversely, corals incubated at normal pH had low calcification rates if the bicarbonate concentration was lowered. These results demonstrate that coral responses to ocean acidification are more diverse than currently thought, and question the reliability of using carbonate concentration or aragonite saturation state as the sole predictor of the effects of ocean acidification on coral calcification.

Bielmyer, G.K., Grosell, M., Bhagooli, R., Baker, A.C., Langdon, C., Gillette, P., and Capo, T.R. Differential effects of copper on three species of scleractinian corals and their algal symbionts (*Symbiodinium* spp.). *Aquatic Toxicology* 97(2): 125-133, 2010.

Notes: Land-based sources of pollution have been identified as significant stressors linked to the widespread declines of coral cover in coastal reef ecosystems over the last 30 years. Metal contaminants, although noted as a concern, have not been closely monitored in these sensitive ecosystems, nor have their potential impacts on coral-algal symbioses been characterized. In this study, three species of laboratory-reared scleractinian corals, *Acropora cervicornis*, *Pocillopora damicornis*, and *Montastraea faveolata* each containing different algal symbionts (*Symbiodinium* A3, C1 and D1a, respectively) were exposed to copper (ranging from 2 to 20 µg/L) for 5 weeks. At the end of the exposure period, copper had accumulated in the endosymbiotic dinoflagellate ("zooxanthellae") and animal tissue of *A. cervicornis* and the animal tissue of *M. faveolata*; however, no copper accumulation was detected in the zooxanthellae or animal tissue of *P. damicornis*. The three coral species exhibited significantly different sensitivities to copper, with effects occurring in *A. cervicornis* and *P. damicornis* at copper concentrations as low as 4 µg/L Copper exposure affected zooxanthellae photosynthesis in *A. cervicornis* and *P. damicornis*, and carbonic anhydrase was significantly decreased in *A. cervicornis* and *M. faveolata*. Likewise, significant decreases in skeletal growth were observed in *A. cervicornis* and *P. damicornis* after copper exposure. Based on preliminary results, no changes in *Symbiodinium* communities were apparent in response to increasing copper concentration. These results indicate that the relationships between physiological/toxicological endpoints and copper accumulation between coral species differ, suggesting different mechanisms of toxicity and/or susceptibility. This may be driven, in part, by differences in the algal symbiont communities of the coral species in question.

Mbije, N.E.J., Spanier, E., and Rinkevich, B. Testing the first phase of the 'gardening concept' as an applicable tool in restoring denuded reefs in Tanzania. *Ecological Engineering* 36(5): 713-721, 2010.

Notes: Studies on coral reef restoration through a two-step coral gardening protocol have lately proved it to be a viable solution for future reef restoration. This involves a first step of gardening small colonies in mid-water nurseries and a second step, their transplantation, upon reaching suitable size, onto the pre-surveyed damaged areas. We established in September 2007 two mid-water nurseries, each holding 10,000 fragments measuring 2 cm average initial size, at 4 m depths (high tide) in Zanzibar and Mafia Islands, Tanzania. Each nursery comprised six species, each of which was represented by three genotypes. During 9 months, we followed developments by analyzing and comparing survivorship and growth rates of fragments between the different nurseries, species and genotypes. A significant difference between species survival and growth rates was observed in acroporid species, in *Pocillopora verrucosa* and *Millepora* sp., which showed better success than *Porites cylindrica*. In both sites, *Millepora* suffered no mortality and other species exhibited low mortality, ranging (per coral genotype) between 3% and 24% in Zanzibar (most cases below 10%) and between 13% and 44% (mostly below 25%) in Mafia Island. Most of fragments' mortality occurred during the first two nursery months. Coral species in Zanzibar nursery also performed better in growth rates than those in Mafia, but in both sites, farmed corals were ready for transplantation just 9 months after the nursery was set up. Economic evaluations involved in the overall nursery set-up and the results indicated that the coral gardening approach could be used in Tanzania to generate large quantities of coral colonies for the restoration of damaged reefs at relatively low cost.

Smith, J.E., Hunter, C.L., and Smith, C.M. The effects of top-down versus bottom-up control on benthic coral reef community structure. *Oecologia* 163(2): 497-507, 2010.

Notes: While climate change and associated increases in sea surface temperature and ocean acidification, are among the most important global stressors to coral reefs, overfishing and nutrient pollution are among the most significant local threats. Here we examined the independent and interactive effects of reduced grazing pressure and nutrient enrichment using settlement tiles on a coral-dominated reef via long-term manipulative experimentation. We found that unique assemblages developed in each treatment combination confirming that both nutrients and herbivores are important drivers of reef community structure. When herbivores were removed, fleshy algae dominated, while crustose coralline algae (CCA) and coral were more abundant when herbivores were present. The effects of fertilization varied depending on herbivore treatment; without herbivores fleshy algae increased in abundance and with herbivores, CCA increased. Coral recruits only persisted in treatments exposed to grazers. Herbivore removal resulted in rapid changes in community structure while there was a lag in response to fertilization. Lastly, re-exposure of communities to natural herbivore populations caused reversals in benthic community trajectories but the effects of fertilization remained for at least 2 months. These results suggest that increasing herbivore populations on degraded reefs may be an effective strategy for restoring ecosystem structure and function and in reversing coral-algal phase-shifts but that this strategy may be most effective in the absence of other confounding disturbances such as nutrient pollution.

Bahartan, K., Zibdah, M., Ahmed, Y., Israel, A., Brickner, I., and Abelson, A. Macroalgae in the coral reefs of Eilat (Gulf of Aqaba, Red Sea) as a possible indicator of reef degradation. *Marine Pollution Bulletin* 60(5): 759-764, 2010.

Notes: The current state of health of the coral reefs in the northern Gulf of Aqaba (Red Sea), notably the Eilat reefs, is under debate regarding both their exact condition and the causes of degradation. A dearth of earlier data and unequivocal reliable indices are the major problems hinder a clear understanding of the reef state. Our research objective was to examine coral-algal dynamics as a potential cause and an indication of reef degradation. The community structure of stony corals and algae along the northern Gulf of Aqaba reveal non-seasonal turf algae dominancy in the shallow Eilat reefs (up to 72%), while the proximate Aqaba reefs present negligible turf cover (<6%). We believe that turf dominancy can indicate degradation in these reefs, based on the reduction in essential reef components followed by proliferation of perennial turf algae. Our findings provide further evidence for the severe state of the Eilat coral reefs.

Lugo-Fernández, A. and Gravois, M. Understanding impacts of tropical storms and hurricanes on submerged bank reefs and coral communities in the northwestern Gulf of Mexico. *Continental Shelf Research* 30(10-11): 1226-1240, 2010.

Notes: A 100-year climatology of tropical storms and hurricanes within a 200-km buffer was developed to study their impacts on coral reefs of the Flower Garden Banks (FGB) and neighboring banks of the northwestern Gulf of Mexico. The FGB are most commonly affected by tropical storms from May through November, peaking in August-September. Storms approach from all directions; however, the majority of them approach from the southeast and southwest, which suggests a correlation with storm origin in the Atlantic and Gulf of Mexico. A storm activity cycle lasting 30-40 years was identified similar to that known in the Atlantic basin, and is similar to the recovery time for impacted reefs. On average there is 52% chance of a storm approaching within 200 km of the FGB every year, but only 17% chance of a direct hit every year. Storm-generated waves 5-25 m in height and periods of 11-15 s induce particle speeds of 1-4 m s^{-1} near these reefs. The wave- current flow is capable of transporting large (~3 cm) sediment particles, uplifting the near-bottom nepheloid layer to the banks tops, but not enough to break coral skeletons. The resulting storm-driven turbulence induces cooling by heat extraction, mixing, and upwelling, which reduces coral bleaching potential and deepens the mixed layer by about 20 m. Tropical storms also aid larvae dispersal from and onto the FGB. Low storm activity in 1994-2004 contributed to an 18% coral cover increase, but Hurricane Rita in 2005 reduced it by 11% and brought coral cover to nearly pre-1994 levels. These results suggest that the FGB reefs and neighboring reef banks act as coral refugia because of their offshore location and deep position in the water column, which shields them from deleterious effects of all but the strongest hurricanes.

Alcolado, P.M., Morgan, I.E., Kramer, P.A., Ginsburg, R.N., Blanchon, P., de la Guardia, E., Kosminin, V., González-Ferrer, S., and Hernández, M. Condition of remote reefs off southwest Cuba. *Ciencias Marinas* 36(2): 179-197, 2010.

Notes: There are few comprehensive studies on the condition of reefs that are remote from direct anthropogenic pressures and, therefore, ecological baseline data are scarce. To help address this deficiency, the community condition of the little-studied remote reefs along a 200-km-long tract bordering the Gulf of Batabano (southwest Cuba) was assessed. The reef-front coral communities (38 sites), where *Montastraea* spp. is the most common coral, were homogeneous along the entire reef tract. The reef-crest coral communities (30 sites), however, could be differentiated into three geographically distinct areas by their abundances of *Acropora palmata* and *Diploria clivosa*; the former predominated at 26 of the 30 reef-crest sites, but most colonies were "standing dead". This observation is similar to the massive declines of acroporid coral populations that have been documented throughout the Caribbean region. Mean coral cover (19-26%) was similar to the regional average (19-23%), but was surprisingly high (72%) at a protected reef-crest site close to an extensive mainland coastal mangrove (Cienaga de Zapata). At this site, *A. palmata* and other acroporids were abundant and healthy, and *Diadema antillarum* density was higher than in the other surveyed areas. Reduced hurricane impact at this more sheltered site may have either circumvented a synergy with overfishing, hurricane destruction, and recruitment failure (widely reported at other degraded reefs), or maintained a high diademid population that facilitated coral recruitment and allowed rapid coral recovery following damage.

Budd, A.F. and Pandolfi, J.M. Evolutionary novelty is concentrated at the edge of coral species distributions. *Science* 328(5985): 1558-1561, 2010.

Notes: Conservation priorities are calculated on the basis of species richness, endemism, and threats. However, areas ranked highly for these factors may not represent regions of maximal evolutionary potential. The relationship between geography and evolutionary innovation was analyzed in a dominant complex of Caribbean reef corals, in which morphological and genetic data concur on species differences. Based on geometric morphometrics of Pleistocene corals and genetically characterized modern colonies, we found that morphological disparity varies from the center to the edge of the Caribbean, and we show that lineages are static at well-connected central locations but split or fuse in edge zones where gene flow is limited. Thus, conservation efforts in corals should focus not only on the centers of diversity but also on peripheral areas of species ranges and population connectivity.

Cantin, N.E., Cohen, A.L., Karnauskas, K.B., Tarrant, A.M., and McCorkle, D.C. Ocean warming slows coral growth in the central Red Sea. *Science* 329(5989): 322-325, 2010.

Notes: Sea surface temperature (SST) across much of the tropics has increased by 0.4 º to 1 ºC since the mid-1970s. A parallel increase in the frequency and extent of coral bleaching and mortality has fueled concern that climate change poses a major threat to the survival of coral reef ecosystems worldwide. Here we show that steadily rising SSTs, not ocean acidification, are already driving dramatic changes in the growth of an important reef-building coral in the central Red Sea. Three-dimensional computed tomography analyses of the massive coral *Diploastrea heliopora* reveal that skeletal growth of apparently healthy colonies has declined by 30% since 1998. The same corals responded to a short-lived warm event in 1941/1942, but recovered within 3 years as the ocean cooled. Combining our data with climate model simulations by the Intergovernmental Panel on Climate Change, we predict that should the current warming trend continue, this coral could cease growing altogether by 2070.

Wilson, S.K., Fisher, R., Pratchett, M.S., Graham, N.A.J., Dulvy, N.K., Turner, R.A., Cakacaka, A., and Polunin, N.V.C. Habitat degradation and fishing effects on the size structure of coral reef fish communities. *Ecological Applications* 20(2): 442-451, 2010.

Notes: Overfishing and habitat degradation through climate change pose the greatest threats to sustainability of marine resources on coral reefs. We examined how changes in fishing pressure and benthic habitat composition influenced the size spectra of island-scale reef fish communities in Lau, Fiji. Between 2000 and 2006 fishing pressure declined in the Lau Islands due to declining human populations and reduced demand for fresh fish. At the same time, coral cover declined and fine-scale architectural complexity eroded due to coral bleaching and outbreaks of crown-of-thorns starfish, *Acanthaster planci*. We examined the size distribution of reef fish communities using size spectra analysis, the linearized relationship between abundance and body size class. Spatial variation in fishing pressure accounted for 31% of the variation in the slope of the size spectra in 2000, higher fishing pressure being associated with a steeper slope, which is indicative of fewer large-bodied fish and/or more small-bodied fish. Conversely, in 2006 spatial variation in habitat explained 53% of the variation in the size spectra slopes, and the relationship with fishing pressure was much weaker (~12% of variation) than in 2000. Reduced cover of corals and lower structural complexity was associated with less steep size spectra slopes, primarily due to reduced abundance of fish <20 cm. Habitat degradation will compound effects of fishing on coral reefs as increased fishing reduces large-bodied target species, while habitat loss results in fewer small-bodied juveniles and prey that replenish stocks and provide dietary resources for predatory target species. Effective management of reef resources therefore depends on both reducing fishing pressure and maintaining processes that encourage rapid recovery of coral habitat.

De'ath, G. and Fabricius, K. Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. *Ecological Applications* 20(3): 840-850, 2010.

Notes: Degradation of inshore coral reefs due to poor water quality is a major issue, yet it has proved difficult to demonstrate this linkage at other than local scales. This study modeled the relationships between large-scale data on water clarity and chlorophyll and four measures of reef status along the whole Great Barrier Reef, Australia (GBR; 12-24ºS). Four biotic groups with different trophic requirements, namely, the cover of macroalgae and the taxonomic richness of hard corals and phototrophic and heterotrophic octocorals, were predicted from water quality and spatial location. Water clarity and chlorophyll showed strong spatial patterns, with water clarity increasing more than threefold from inshore to offshore waters and chlorophyll decreasing approximately twofold from inshore to offshore and approximately twofold from south to north. Richness of hard corals and phototrophic octocorals declined with increasing turbidity and chlorophyll, whereas macroalgae and the richness of heterotrophic octocorals increased. Macroalgal cover experienced the largest water quality effects, increasing fivefold with decreasing water clarity and 1.4-fold with increasing chlorophyll. For each of the four biota, 45% of variation was predictable, with water quality effects accounting for 18-46% of that variation and spatial effects accounting for the remainder. Effects were consistent with the trophic requirements of the biota, suggesting that both macroalgal cover and coral biodiversity are partially controlled by energy supply limitation. Throughout the GBR, mean annual values of >10 m Secchi disk depth (a measure of water clarity) and <0.45 g/L chlorophyll were associated with low macroalgal cover and high coral richness, indicating these values to be potentially useful water quality guidelines. The models predict that on the 22.8% of GBR reefs where guideline values are currently exceeded, water quality improvement, e.g., by minimizing agricultural runoff, should reduce macroalgal cover on average by 39% and increase the richness of hard corals and phototrophic octocorals on

average by 16% and 33%, respectively (all else being equal). Such guidelines may help focus efforts to implement effective pollution reduction and integrated coastal management policies for the GBR and other Indo-Pacific coral reefs.

Huang, M.-H. and Ou, C.-H. Precious coral fisheries management in Taiwan – Past, present and future. *Marine Policy* 34(5): 1002-1009, 2010.

Notes: Taiwan used to have the biggest precious coral fisheries industry in the world. However, due to changes in the fishery, including increased fishing restrictions and the replacement of obsolete vessels, the scale of the industry had been gradually reduced since 1979. Unfortunately, the initiative proved to be poorly managed and resulted in an increase in illegal, unreported and unregulated (IUU) coral fishing. This forced the government to review and amend the precious coral fisheries management regulations, which had been in place for decades. The Taiwanese government introduced stringent monitoring, control and surveillance (MCS) management methods, already used in deep water fisheries, as a precautionary approach. At the same time, an investigation and evaluation of existing resources was carried out. Together, these initiatives were introduced in order to encourage the domestic industry to adopt the concept of ecosystem-based fishery management. This paper reviews the development of precious coral fisheries management in Taiwan, discusses the causes of illegal coral fisheries and looks at the reasons for adjustments to the current management system. Further issues that need to be resolved will also be discussed based on the relative success of the management implementation following the adjustments. Finally, research topics and priority initiatives will be proposed for the future management of Taiwan's precious coral fisheries.

Tissot, B.N. *et al.* How U.S. ocean policy and market power can reform the coral reef wildlife trade. *Marine Policy* 34(6): 1385-1388, 2010.

Notes: As the world's largest importer of marine ornamental species for the aquaria, curio, home decor, and jewelry industries, the United States has an opportunity to leverage its considerable market power to promote more sustainable trade and reduce the effects of ornamental trade stress on coral reefs worldwide. Evidence indicates that collection of some coral reef animals for these trades has caused virtual elimination of local populations, major changes in age structure, and promotion of collection practices that destroy reef habitats. Management and enforcement of collection activities in major source countries such as Indonesia and the Philippines remain weak. Strengthening US trade laws and enforcement capabilities combined with increasing consumer and industry demand for responsible conservation can create strong incentives for improving management in source countries. This is particularly important in light of the March 2010 failure of the parties to the Convention on International Trade in Endangered Species (CITES) to take action on key groups of corals.

Wilson, S.K. *et al.* Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. *Journal of Experimental Biology* 213(6): 894-900, 2010. O / A

Notes: Expert opinion was canvassed to identify crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. Scientists that had published three or more papers on the effects of climate and environmental factors on reef fishes were invited to submit five questions that, if addressed, would improve our understanding of climate change effects on coral reef fishes. Thirty-three scientists provided 155 questions, and 32 scientists scored these questions in terms of: (i) identifying a knowledge gap, (ii) achievability, (iii) applicability to a broad spectrum of species and reef habitats, and (iv) priority. Forty-two per cent of the questions related to habitat associations and community dynamics of fish, reflecting the established effects and immediate concern relating to climate-induced coral loss and habitat degradation. However, there were also questions on fish demographics, physiology, behaviour and management, all of which could be potentially affected by climate change. Irrespective of their individual expertise and background, scientists scored questions from different topics similarly, suggesting limited bias and recognition of a need for greater interdisciplinary and collaborative research. Presented here are the 53 highest-scoring unique questions. These questions should act as a guide for future research, providing a basis for better assessment and management of climate change impacts on coral reefs and associated fish communities.

Mydlarz, L.D., McGinty, E.S., and Harvell, C.D. What are the physiological and immunological responses of coral to climate warming and disease? *Journal of Experimental Biology* 213(6): 934-945, 2010. O / A

Notes: Coral mortality due to climate-associated stress is likely to increase as the oceans get warmer and more acidic. Coral bleaching and an increase in infectious disease are linked to above average sea surface temperatures. Despite the uncertain future for corals, recent studies have revealed physiological mechanisms that improve coral resilience to the effects of climate change. Some taxa of bleached corals can increase heterotrophic food intake and exchange symbionts for more thermally tolerant clades; this plasticity can increase the probability of surviving lethal thermal stress. Corals can fight invading pathogens with a suite of innate immune responses that slow and even arrest pathogen growth and reduce further tissue damage. Several of these responses, such as the melanin cascade, circulating amoebocytes and antioxidants, are induced in coral hosts during pathogen invasion or disease. Some components of immunity show thermal resilience and are enhanced during temperature stress and even in bleached corals. These examples suggest some plasticity and resilience to cope with environmental change and even the potential for evolution of resistance to disease. However, there is huge variability in responses among coral species, and the rate of climate change is projected to be so rapid that only extremely hardy taxa are likely to survive the projected changes in climate stressors.

Smith, T.B., Blondeau, J., Nemeth, R.S., Pittman, S.J., Calnan, J.M., Kadison, E., and Gass, J. Benthic structure and cryptic mortality in a Caribbean mesophotic coral reef bank system, the Hind Bank Marine Conservation District, US Virgin Islands. *Coral Reefs* 29(2): 289-308, 2010. O / A

Notes: Coral reef banks may form an important component of mesophotic coral ecosystems (MCEs) in the Caribbean, but remain poorly explored relative to shallower reefs and mesophotic habitats on slopes and walls. Consequently, the processes structuring mesophotic coral reef communities are not well understood, particularly the role of disturbance. A large and regionally important mesophotic system, the Hind Bank Marine Conservation District (MCD), St. Thomas, USVI, was systematically surveyed. Data were used to construct a comprehensive benthic habitat map for the MCD, describe the abiotic and biotic components of the benthos among habitats, and investigate patterns of coral health among habitats. Two-thirds of the MCD (23.6 km^2) was found to be dense coral reef (Coral Cover = 24.1%) dominated by the *Montastraea annularis* species complex. Coral reef ecosystems were topographically complex, but could be classified into distinct habitat types, including high coral banks (35.8% of the MCD) and two large novel coral reef habitat types corresponding to an extremely flat basin (18%) and a highly rugose hillock basin (6.5%), containing thousands of coral knolls (2-10 m high). An extreme disease event with undescribed signs of mortality occurred on 47% of coral reefs and reached a high prevalence in affected areas (42.4% ± 6.3 SE, $N = 26$). The disease was significantly clustered in the basin habitats of the western MCD (global Moran's I = 0.32, $P < 0.01$). Observations of the spatial pattern suggested that the driver was specific to the basin habitats and may have been caused by a coherent abiotic event.

Kahng, S.E., Garcia-Sais, J.R., Spalding, H.L., Brokovich, E., Wagner, D., Weil, E., Hinderstein, L., and Toonen, R.J. Community ecology of mesophotic coral reef ecosystems. *Coral Reefs* 29(2): 255-275, 2010. O / A

Notes: Given the global degradation of shallow-water coral reef ecosystems resulting from anthropogenic activities, mesophotic coral reef ecosystems (MCEs) are gaining attention because they are generally considered a de facto refuge for shallow-water species. Despite their inferred importance, MCEs remain one of the most understudied reef habitats, and basic information on the taxonomic composition, depth range, habitat preferences, and abundance and distribution of MCE taxa is scarce. The processes that structure these communities are virtually unknown. Here, we provide a review of what is known about MCEs community ecology and outline essential gaps in our knowledge of these deeper water coral reef ecosystems. The primary findings of this review are as follows: (1) many dominant shallow-water species are absent from MCEs; (2) compared to shallow reefs, herbivores are relatively scarce, perhaps due to limited habitat complexity at depth; (3) changes in the dominant photosynthetic taxa with depth suggest adaptation and specialization to depth; (4) evidence regarding the importance of heterotrophy for zooxanthellate corals at depth is conflicting and inconclusive; and (5) decreased light with depth, but not temperature, appears to be the primary factor limiting the depth of MCEs. The majority of research done to date has been performed in the Caribbean, where some generalization can be made about the community structure and distribution of MCEs. The larger and more diverse Indo-Pacific remains largely unexplored with no apparent generalizations from the few sites that have been comparatively well studied. For MCEs, large gaps in knowledge remain on fundamental

aspects of ecology. Advanced technologies must be harnessed and logistical challenges overcome to close this knowledge gap and empower resource managers to make informed decisions on conserving shallow-water and mesophotic coral reef ecosystems.

Bongaerts, P., Ridgway, T., Sampayo, E.M., and Hoegh-Guldberg, O. Assessing the 'deep reef refugia' hypothesis: focus on Caribbean reefs. *Coral Reefs* 29(2): 309-327, 2010. O / A

Notes: Coral reefs in shallow-water environments (<30 m) are in decline due to local and global anthropogenic stresses. This has led to renewed interest in the 'deep reef refugia' hypothesis (DRRH), which stipulates that deep reef areas (1) are protected or dampened from disturbances that affect shallow reef areas and (2) can provide a viable reproductive source for shallow reef areas following disturbance. Using the Caribbean as an example, the assumptions of this hypothesis were explored by reviewing the literature for scleractinian corals – the reef framework builders on tropical reefs. Although there is evidence to support that deep reefs (>30 m) can escape the direct effects of storm-induced waves and thermal bleaching events, deep reefs are certainly not immune to disturbance. Additionally, the potential of deep reefs to provide propagules for shallow reef areas seems limited to 'depth-generalist' coral species, which constitute only ~25% of the total coral biodiversity. Larval connectivity between shallow and deep populations of these species may be further limited due to specific life history traits (e.g., brooding reproductive strategy and vertical symbiont acquisition mode). This review exposes how little is known about deep reefs and coral reproduction over depth. Hence, a series of urgent research priorities are proposed to determine the extent to which deep reefs may act as a refuge in the face of global reef decline.

Futch, J.C., Griffin, D.W., and Lipp, E.K. Human enteric viruses in groundwater indicate offshore transport of human sewage to coral reefs of the Upper Florida Keys. *Environmental Microbiology* 12(4): 964-974, 2010.

Notes: To address the issue of human sewage reaching corals along the main reef of the Florida Keys, samples were collected from surface water, ground-water and coral [surface mucopolysaccharide layers (SML)] along a 10 km transect near Key Largo, FL. Samples were collected semi-annually between July 2003 and September 2005 and processed for faecal indicator bacteria (faecal coliform bacteria, enterococci and *Clostridium perfringens*) and human-specific enteric viruses (enterovirus RNA and adenovirus DNA) by (RT)-nested polymerase chain reaction. Faecal indicator bacteria concentrations were generally higher nearshore and in the coral SML. Enteric viruses were evenly distributed across the transect stations. Adenoviruses were detected in 37 of 75 samples collected (49.3%) whereas enteroviruses were only found in 8 of 75 samples (10.7%). Both viruses were detected twice as frequently in coral compared with surface water or groundwater. Offshore, viruses were most likely to be found in groundwater, especially during the wet summer season. These data suggest that polluted groundwater may be moving to the outer reef environment in the Florida Keys.

Sutherland, K.P., Porter, J.W., Turner, J.W., Thomas, B.J., Looney, E.E., Luna, T.P., Meyers, M.K., Futch, J.C., and Lipp, E.K. Human sewage identified as likely source of white pox disease of the threatened Caribbean elkhorn coral, *Acropora palmata*. *Environmental Microbiology* 12(5): 1122-1131, 2010.

Notes: Caribbean elkhorn coral, *Acropora palmata*, has been decimated in recent years, resulting in the listing of this species as threatened under the United States Endangered Species Act. A major contributing factor in the decline of this iconic species is white pox disease. In 2002, we identified the faecal enterobacterium, *Serratia marcescens*, as an etiological agent for white pox. During outbreaks in 2003 a unique strain of *S. marcescens* was identified in both human sewage and white pox lesions. This strain (PDR60) was also identified from corallivorious snails (*Coralliophila abbreviata*), reef water, and two non-acroporid coral species, *Siderastrea siderea* and *Solenastrea bournoni*. Identification of PDR60 in sewage, diseased *Acropora palmata* and other reef invertebrates within a discrete time frame suggests a causal link between white pox and sewage contamination on reefs and supports the conclusion that humans are a likely source of this disease.

Vezzulli, L., Previati, M., Pruzzo, C., Marchese, A., Bourne, D.G., and Cerrano, C. *Vibrio* infections triggering mass mortality events in a warming Mediterranean Sea. *Environmental Microbiology* 12(7): 2007-2019, 2010.

Notes: Mass mortality events of benthic invertebrates in the temperate north-western (NW) Mediterranean Sea have been observed in recent seasons. A 16 month *in situ* study in the Ligurian Sea (NW Mediterranean Sea) demonstrated that the occurrence of *Paramuricea clavata* mortality episodes were concomitant to a condition of prolonged high sea surface temperatures, low chlorophyll concentrations and the presence of culturable *Vibrio* spp. in seawater. The occurrence of *Vibrio* spp. at the seasonal scale was correlated with temperature; with few vibrios retrieved on specific media when the temperature dropped below 18°C and a sharp increase of vibrios abundance (up to 3.4×10^4 MPNl^{-1}) when the temperature was greater than or equal to 22°C. Phylogenetic and phenotypic analysis of *Vibrio* isolates associated with healthy and diseased *P. clavata* colonies collected during a mortality episode showed that these bacteria were significantly more abundant in diseased than in healthy corals and were related to the *V. harveyi*, *V. splendidus* and *V. coralliilyticus* groups, the latter only identified in diseased organisms. Inoculation of bacterial isolates from these groups onto healthy *P. clavata* in aquaria caused disease signs and death in a range of *Vibrio* concentrations, temperature values and trophic conditions consistent with those recorded in the field. It is concluded that *Vibrio* infections may act as an additional triggering mechanism of mass mortality events in the coastal Mediterranean Sea and that their occurrence is climate-linked. Predicted global warming leading to long-lasting hot summer periods together with stratification resulting in energetic constraints represent a major threat to the survival of benthic invertebrates in the temperate NW Mediterranean Sea due to potential disease outbreak associated with *Vibrio* pathogens.

Linares, C. and Doak, D.F. Forecasting the combined effects of disparate disturbances on the persistence of long-lived gorgonians: a case study of *Paramuricea clavata*. *Marine Ecology Progress Series* 402: 59-68, 2010.

Notes: The combined effects of disparate impacts on population health are a continuing problem in risk assessment and management for threatened species. Populations of red gorgonian *Paramuricea clavata* in the NW Mediterranean Sea are threatened both by chronic and localized increases in mortality due to high diving activity and by widespread but episodic mass mortality events related to climatic anomalies. Using demographic data obtained from 3 populations (2 under contrasting levels of diving and one affected by a 1999 mass mortality event), we developed size-structured matrix models to forecast the long-term consequences of both disturbances and their combined effects. When we considered only the effects of diver damage, our results showed that population stability could be achieved with an increase in the annual survival of adult colonies of between 3 and 7%, demonstrating the need for diving reduction in the study locations, where there are estimated to be between 30000 and 70000 dives yr^{-1}. Modeling the effects of mass mortality events alone showed a low annual population growth rate (0.886) and near certain extinction risk over even short time scales. Considering these 2 types of impacts together, we found that the effects of mass mortality events aggravate the decline in gorgonian populations subjected to high diving impact, reaching the extinction threshold after 36 to 55 yr under the actual frequency of mass mortality events. Simulated reduction of diving effects dramatically increased the time to quasi-extinction for populations subjected to realistic frequencies of mass mortality events. Our simulations reveal the need of management actions to ensure the gorgonian viability in the face of climate change, and suggest that management of more controllable impacts, such as diving, can help buffer populations against the less controllable effects of climate change.

Linares, C., Bianchimani, O., Torrents, O., Marschal, C., Drap, P., and Garrabou, J. Marine Protected Areas and the conservation of long-lived marine invertebrates: the Mediterranean red coral. *Marine Ecology Progress Series* 402: 69-79, 2010.

Notes: Intensive harvesting has caused important shifts in the size structure of the Mediterranean red coral *Corallium rubrum*, and continues to hinder the total recovery of exploited populations. Marine Protected Areas (MPAs) offer an excellent opportunity to observe their recovery in the absence of fishing pressures. In this study, we analysed the demographic structure of red coral populations from 3 of the oldest Mediterranean MPAs. The population structures at the beginning of each reserve and after 30 yr of similar management efforts were also forecasted. The 3 MPAs displayed higher size values than those reported for most of the shallow populations and deep-dwelling populations. Differences in the observed size distributions were more closely related to the structure at the beginning of the reserve than to the number of years of protection. The estimated future size distributions showed a significant increase in large colonies; however, the maximum values predicted are far from those measured in pristine populations. Comparisons of harvested and protected populations using different

parameters allowed us to identify the percentages of colonies with basal diameter greater than 7 mm or colony height greater than 100 mm as the most useful descriptors for evaluating the conservation status of each population. The vulnerability of long-lived marine invertebrates to disturbances is due to their slow population dynamics, hence the importance of active management within MPAs to promote delayed but long-term positive effects on these species. This study provides helpful information for the evaluation of the effectiveness of management measures for coral populations.

Schutte, V.G.W., Selig, E.R., and Bruno, J.F. Regional spatio-temporal trends in Caribbean coral reef benthic communities. *Marine Ecology Progress Series* 402: 115-122, 2010. O / A

Notes: Coral cover has declined on reefs worldwide with particularly acute losses in the Caribbean. Despite our awareness of the broad-scale patterns and timing of Caribbean coral loss, there is little published information on: (1) finer-scale, subregional patterns over the last 35 yr, (2) regional-scale trends since 2001, and (3) macroalgal cover changes. We analyzed the spatio-temporal trends of benthic coral reef communities in the Caribbean using quantitative data from 3777 coral cover surveys of 1962 reefs from 1971 to 2006 and 2247 macroalgal cover surveys of 875 reefs from 1977 to 2006. A subset of 376 reefs was surveyed more than once (monitored). The largest 1 yr decline in coral cover occurred from 1980 to 1981, corresponding with the beginning of the Caribbean-wide *Acropora* spp. white band disease outbreak. Our results suggest that, regionally, coral cover has been relatively stable since this event (i.e. from 1982 to 2006). The largest increase in macroalgal cover was in 1986, 3 yr after the regional die-off of the urchin grazer *Diadema antillarum* began. Subsequently, macroalgal cover declined in 1987 and has been stable since then. Regional mean (±1 SE) macroalgal cover from 2001 to 2005 was 15.3 ± 0.4% (n = 1821 surveys). Caribbean-wide mean (±1 SE) coral cover was 16.0 ± 0.4% (n = 1547) for this same time period. Both macroalgal and coral cover varied significantly among subregions from 2001 to 2005, with the lowest coral cover in the Florida Keys and the highest coral cover in the Gulf of Mexico. Spatio-temporal patterns from the subset of monitored reefs are concordant with the conclusions drawn from the entire database. Our results suggest that coral and macroalgal cover on Caribbean reef benthic communities has changed relatively little since the mid-1980s.
