The scale and epistemology of coral bleaching in Papua New Guinea.

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Abstract:

Coral bleaching events around the world appear to be increasing in frequency and severity, with the 2002 bleaching events reportedly causing greater coral mortality than those in 1998. The primary driver is global (i.e. excessive CO_2 production in industrial countries), while the impact is local, and highly variable. Ecological, and consequent socio-economic impacts of coral bleaching may not be measurable in relatively lightly bleached areas, such as Milne Bay, Papua New Guinea, for perhaps 10 or more years, though medium to long term (10-50 years) impacts might well be dramatic. However recent work indicates that the nature of bleaching, and bleaching-induced mortality, is extremely complex, and there is still some debate on issues such as the potential for corals and their symbionts to adapt to rising sea temperatures. There may be a level of general recovery in the long term (> 50 years), due to differential survival and expansion of more resistant species, but a significant proportion of the world's reefs are unlikely to ever again resemble pre-1980s community structure. This issue illustrates the importance of considerations of scale, both in space and time, in assessing the impact of this increasingly dramatic dimension of climate change.

Coral bleaching also raises significant epistemological issues. It is a new phenomenon, and as such there is typically no suitable explanatory framework within indigenous cosmologies in coastal Melanesia. How do Pacific Islanders explain coral bleaching? How does the small amount of scientific information that filters out to them become incorporated into local understandings? On Malie Island in the Lihir group in Papua New Guinea, bleaching has been blamed on submarine tailings from the nearby gold mine. The same conclusion was also reached on Tanga Island, which is much further away.

Most Pacific Islands folk taxonomies have relatively few categories for corals, and their understandings of coral biology and ecology are very different from those of biologists. Given the incomplete nature of scientific knowledge of coral bleaching, this area holds many challenges, both for the use of indigenous knowledge in ecosystem assessments, and for marine resource management programs in general.

Introduction

This paper addresses the following questions:

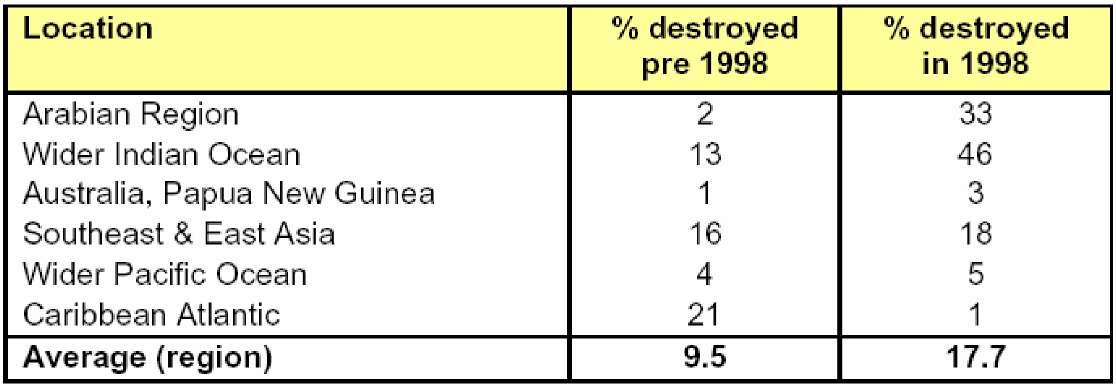
1. How severe is coral bleaching likely to be in Papua New Guinea (PNG) within the next 50 years, and how will it best be monitored?
2. How much is coral bleaching going to impact on coral reef ecosystem services, especially fishery production, in PNG and elsewhere?
3. What will most coastal Papua New Guineans make of coral bleaching, in terms of local understandings of coral reef ecology, and
4. How can information most effectively be exchanged between international scientists and rural reef owners in the interest of mitigating losses of ecosystem services as a result of bleaching?

In the course of answering these questions I will review the latest scientific literature on coral bleaching, contextualise it in terms of likely levels of coral mortality, and discuss probable impacts on fisheries and other reef ecosystem services over the next 50 years. I will review local knowledge about corals in Western Melanesia, and local conceptualisations of the place of corals in coral reefs, and will discuss the challenges involved in establishing a meaningful communication between local reef owners and coral reef scientists, in the interests of mitigating damage to coral reef ecosystem services in PNG.

Climate Change and Coral Bleaching – the state of scientific knowledge

Reef-building corals bleach, i.e. expel their symbiotic Zooxanthellae algae (*Symbiodinium* spp), when their maximum thermal tolerance threshold is reached under high light conditions. These conditions result in the breakdown of the photosynthesis process (Photosystem II: Warner *et al.* 1999) via a process referred to as photoinhibition, resulting in the production of excessive quantities of Oxygen free radicals, which in turn leads to the expulsion of the algal symbionts from their host coral tissues. Most corals live in temperature regimes very close (often within one degree Centigrade) to their maximum thermal tolerance (Coles and Brown 2003). If a sea temperature increase of one degree above this threshold lasts for less than two weeks, most corals recover, and their tissues become repopulated with algal cells. Excursions of the ambient seawater temperature above the maximum threshold for longer periods can and do lead to mortality of corals. Mass bleaching events have tended to correlate strongly with summer sea surface temperature maxima, and the most dramatic episodes have corresponded to the El Nino cycle, when summer maxima substantially exceed the average maximum for a given location. Such increases above the average are measured in degree heating weeks or months. A review of past SST and bleaching data indicates that 12 degree heating weeks is sufficient stress to kill around 90% of the coral cover on a reef (Hoegh-Guldberg and Hoegh-Guldberg 2004). More recent work (e.g. Berkelmans *et al.* 2004) has shown that the maximum temperature over any three day period (Max3d SST) is a more reliable predictor of coral bleaching.

Within the last 20 years there have been six major global cycles of mass coral bleaching. Coral bleaching has been observed and reported since the early 20th century, but only generated widespread scientific and public concern after the 1997/1998 bleaching event, which killed off large numbers of corals on many reefs around the world (Wilkinson 1999). Indeed on some reefs, such as in the Chagos Islands in the Indian Ocean, 100% coral mortality was recorded down to 30 metres (Sheppard *et al.* 2002). Prior to 1998, bleaching events were responsible for killing an average of 9.5% of coral cover across all regions monitored by the Global Coral Reef Monitoring Network. After 1998, the warmest year on record, this figure shot up to 17.7% (Figure 1). In 2002 another massive bleaching episode occurred on the Great Barrier Reef, which in intensity and extent actually eclipsed the 1998 event (Berkelmans et al 2004, Hoegh-Guldberg and Hoegh-Guldberg 2004). Some scientists forecast that it will not be long before bleaching events are seen on an annual basis across the tropics (Hoegh-Guldberg and Hoegh-Guldberg 2004).



Location	% destroyed pre 1998	% destroyed in 1998
Arabian Region	2	33
Wider Indian Ocean	13	46
Australia, Papua New Guinea	1	3
Southeast & East Asia	16	18
Wider Pacific Ocean	4	5
Caribbean Atlantic	21	1
Average (region)	**9.5**	**17.7**

Figure 1 (From Hoegh-Guldberg and Hoegh-Guldberg 2004)

Despite the large body of evidence supporting the dominant link between temperature and coral bleaching, forecasting the extent to which corals will bleach over the next century is an extremely complex matter, and not without debate. Corals and their zooxanthellae symbionts have evolved to tolerate a wide range of temperatures, including substantial intra-specific adaptation across latitudinal, depth, and other environmental gradients (Berkelmans 2002, Coles and Brown 2003). There is also now a large literature on the ways in which corals have acclimated or adapted to changing conditions including increasing temperatures, though there is still great uncertainty as to the rate at which acclimation or adaptation is likely to proceed and whether or not it will keep pace with rises in SSTs forecast by various global warming models (Hoegh-Guldberg 1999, Wilkinson 1999, Hoegh-Guldberg and Hoegh-Guldberg 2004). The most recent and comprehensive review of the research on acclimation and adaptation is by Coles and Brown (2003). This review outlines the various physiological mechanisms that impart resistance to damage caused by the breakdown of Photosystem II under high temperature and light conditions, enabling corals to survive. These mechanisms include the following:

1. Non-photochemical Quenching (NPQ) – a cellular mechanism whereby excess excitation energy that would otherwise result in the breakdown of the photosynthesis process and generation of free radicals is dissipated as heat via the reversible interconversion of the xanthophylls, diadinoxanthin and diatoxanthin.

2. Fluorescent coral pigments, which reflect and/or fluoresce absorbed light and thereby reduce photoinhibition. However these are easily denatured by elevated sea temperatures (Dove, cited in Coles and Brown 2003) and therefore may not be as important as previously assumed.
3. Heat shock proteins, which help to reduce damage by refolding reversibly heat damaged proteins.
4. Production of various superoxidases, which reduce damage from Oxygen free radicals.

In addition to the above mechanisms, the Adaptive Bleaching Hypothesis (ABH) posits that temperature sensitive zooxanthellae varieties that are lost during sub-lethal bleaching episodes can be replaced by more temperature tolerant varieties. The findings of a transplantation experiment published in Nature by Baker (2001) were interpreted as providing support for this idea, but this interpretation has been regarded with scepticism or effectively dismissed by others in the field (Coles and Brown 2003, Hoegh-Guldberg and Hoegh-Guldberg 2004).

There is limited empirical evidence from between year comparisons of particular reefs that recovery leads to an increase in tolerance to thermal stress among surviving corals (e.g. Guzman and Cortez 2001, Glynn *et al.* 2001), but the findings of the latter study are treated with scepticism by Hoegh-Guldberg and Hoegh-Guldberg (2004) on the grounds that temperature conditions were not the same between years. The recent study by Berkelmans *et al.* (2004) which compares levels of bleaching between 1998 and 2002 unfortunately works at a large scale which does not allow any assessment of the potential for acclimation or adaptation between years. The overall higher level of bleaching across the Great Barrier Reef in 2002 however does not give much scope for optimism.

In addition to the above mechanisms, it has been proposed that turbid environments may protect corals living in turbid environments from bleaching due to reduced light penetration and could therefore serve as refugia from which bleached areas can subsequently be repopulated (Meesters *et al.* 2002). Similarly, corals in reef zones that are flushed by strong ocean currents tend to bleach less than those in calmer zones and would therefore survive longer and potentially supply larvae to areas where mortality is high (Aronson *et al.* 2002, West and Salm 2003, Berkelmans *et al.* 2004).

Despite the fact that many corals do recover following bleaching episodes, there are many important sub-lethal impacts of bleaching. These include reduced vitality and growth, calcification rate and repair capability, increased susceptibility to disease, and reduced (or completely suspended) reproductive output (i.e. many corals fail to undergo gametogenesis and spawning following a bleaching episode). Recovery from sublethal bleaching episodes has been found to take more than a year in some cases (Done 1999). Thus as global warming accelerates, and summer temperatures exceed normal maxima on an annual basis (Hoegh-Guldberg 1999, Hoegh-Guldberg and Hoegh-Guldberg 2004), the cumulative impact of such annual stresses will lead to higher levels of mortality for any given number of degree heating weeks or 3-day maxima.

On the Great Barrier Reef at least, average SSTs are expected to rise by 1.2 to 1.9 degrees Centigrade by 2050, flowing mid-range IPCC scenarios (Done *et al.* 2003) and under these conditions, based on bleaching patterns to date, substantial acclimatisation / adaptation will be required to prevent a massive decline in coral cover by 2050. While most scientists acknowledge the potential for adaptation and acclimatisation, most are non-committal about the likely speed at which it might occur, and Hoegh-Guldberg and Hoegh-Guldberg (2004) are highly sceptical that it will keep up with the forecast rate of temperature change, and as such are advocating drastic reductions in greenhouse gas emissions immediately. The fact that the level of mortality caused by the 2002 bleaching event on the Great Barrier Reef significantly exceeded that caused by all other preceding bleaching events, including 1998, is perhaps as good an indication as any of the likely trajectory of bleaching around the world in the next two or three decades.

Bleaching in Papua New Guinea

There have been few published studies on coral bleaching or SST modelling in PNG or the Western Pacific (e.g. Davies *et al.* 1997, Srinivasan 2000), and these provide very little material on which to base any sort of realistic attempt at forecasting the frequency and severity of bleaching in the future. Recent wide-ranging surveys carried out in Milne Bay (Allen *et al.* 2003) show most reefs to be in excellent condition, with high cover of healthy corals at most sites. The surveys conducted at seven locations around PNG by the Wildlife Conservation Society included measurements of percent live hard coral cover, which ranged from around 25% to 45% across all sites (Cinner *et al.* 2002a,b,c, Marnane *et al.*2002a,b,c). However these were one-off surveys that would not have been able to assess bleaching-induced mortality (or post-bleaching recovery), or for that matter make any other kind of longitudinal comparison.

An Internet search yielded a number of reports of bleaching for PNG (Appendix 1). Bleaching episodes have been reported for 1982/3 (Srinivasan 2000), early 1996 (Hair 1996, Davies et al. 1997, Srinivasan 2000, Appendix 1), April to June 1998 (Srinivasan 2000, Quinn 2002), early 1999, early 2000 (Srinivasan 2000, Appendix 1), and late 2000 and early 2001 (Rotmann 2001). The early 1996 event, which corresponded to a 1.29 degrees Centigrade anomaly, appears to have been the most widely reported and severe bleaching episode to date in PNG. Davies *et al.* (1997) report quite extensive bleaching (>50%) at some sites in Milne Bay for the 1996 event. Rotmann (2001) also reports very high levels of bleaching (average around 50% and up to 72% at some sites) at Lihir and Tanga for late 2000 / early 2001. While both these studies report on some monitoring of recovery and/or mortality, this has not yet been done on a systematic basis, and a great deal more such observations will be required to build a useful picture of the impact of bleaching in PNG to date.

The pattern that emerges from the above data is that coral bleaching is indeed occurring on reefs in PNG, but that the pattern of bleaching is quite different from that on the Great Barrier Reef and other higher latitude locations. Bleaching events in PNG appear to have been occurring closer together in time, are not as consistently linked to El Nino weather patterns, and so far have been apparently less catastrophic in severity and extent (although the levels of bleaching reported by Rotmann are clearly severe). In places where sediment runoff from land clearing is significant, the combined stress effect is likely to increase mortality greatly. A regression against monthly SST anomalies performed by Davies et al. (1997) indicated an increase of 0.261 degrees Centigrade between 1956 and 1996 (Fig. 2). Based on the frequency of reported bleaching events around PNG over the last 10 years, and assuming adaptation/acclimation will be as slow as is apparent from the foregoing review, the likelihood of annual bleaching events occurring from now on seems high.

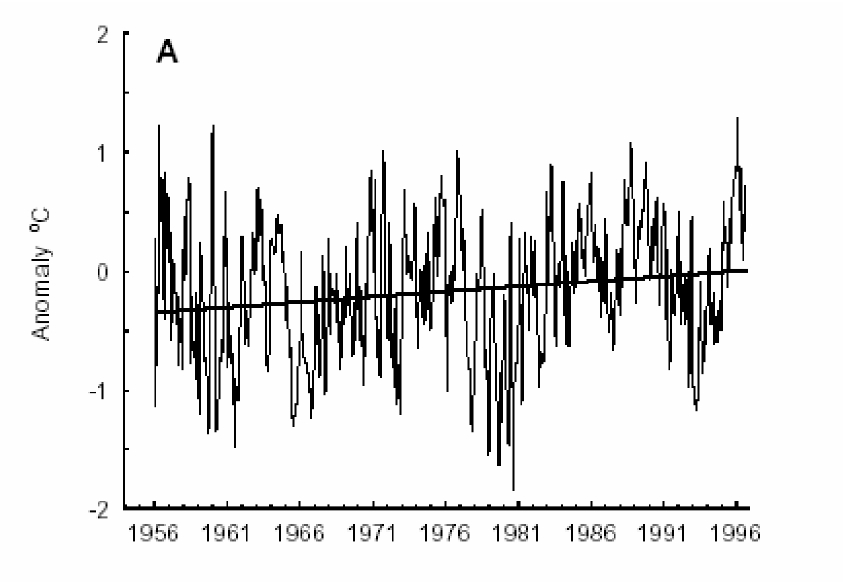


Figure 2. a regression fitted to SST anomalies from 1956 to 1996 gives a total increase of 0.261^{0}C (From Davies et al 1997).

The Impact of Coral Bleaching on fishery production

While impacts of coral bleaching on the tourism industry on the Great Barrier Reef occupy the minds of Australia's leading coral scientists (Hoegh-Guldberg and Hoegh-Guldberg 2004) and policy makers, it is impacts on fisheries that will be of most concern to Papua New Guineans. There is a small diving tourism industry in PNG but it is insignificant economically compared to the value of artisanal and subsistence fisheries.

Fin fish

Most recent short terms studies of the impact of bleaching on coral reef fish community structure and fishery production have reported surprisingly low impacts (Lindahl *et al.* 2001, Spalding and Jarvis 2002, Grandcourt and Cesar 2003). Most of these studies showed that while abundances of obligate coral feeders such as chaetodontids declined, herbivores generally increased, and overall biomass and diversity did not change significantly. This is mainly because overall abundance of reef fishes is correlated more with structural complexity of reefs than with percent live coral cover (Jones and Syms 1998, Done 1999). However long-term prognoses for coral bleaching indicate that coral reef structure will inevitably reduce in complexity as corals die, and bio-erode. The reduction in carbonate saturation state of global seas as they absorb more and more CO2 will also contribute to this decline in structural complexity (Kleypas *et al.* 1999, Done 1999). Similarly increases in frequency and intensity of storms will accelerate the structural degradation of reefs in combination with these other factors (Done 1999).

Invertebrates

It is much harder to forecast the potential impacts of increased coral bleaching, and associated reef degradation on important Melanesian subsistence and artisanal fisheries such as trochus (*Trochus niloticus*), Beche-de-mer (various Holothurians), crayfish (*Panulirus* spp) and the many species of clams and oysters commonly harvested in both reef and mangrove zones by women. Most of these organisms are herbivores, filter-feeders or detritivores and there is insufficient information available to judge how soon they are likely to be impacted by climate change. One conspicuous exception applies to most *Tridacna* (giant clam) species, which depend on zooxanthellae and have already been observed to bleach during SST anomalies. It is likely that these will be impacted sooner than the other groups.

The place of coral in Melanesian environmental knowledge

While most Melanesian coastal languages include richly elaborated taxonomies for reef fish (Akimichi 1991, Foale 1998, Kinch 1999), there are relatively few local taxa for “coral”. There are two common Austronesian generic categories for coral: *Laje* (branching) and *Bunga* (smooth, round) (Osmond *et al.* 2003), but relatively few specific categories beneath these. The largest number of terms that can be found for hard corals is around 11, for the Marovo language in Solomon Islands (Hviding, in press). The etymologies of most of these terms reveal very general descriptors of shape, size or broad habitat criteria. The same pattern is likely to apply to most other Austronesian taxonomies. On Lihir, the generic term for coral is *Rets*, and within this are about 7 sub-categories each of which are binomials consisting of *Rets* plus a descriptor that denotes growth form (branching, plate, round etc). Given the utilitarian nature of most folk taxonomies (Berlin *et al.* 1973) this makes sense in terms of the relative importance (economic, ritual or otherwise) that corals have for most coastal Melanesians. Diving goggles were not introduced to the area until the 19th century, and much of the knowledge that has been gained by observing organisms with these has been gained in the context of commercial fisheries that were organised by foreign traders. Many organisms that were not traditionally exploited pre-colonially have English or trade names. Because beche-de-mer was not eaten traditionally in most parts of Melanesia most of the species that are harvested in PNG and the Solomon Islands are referred to by their trade names (e.g. “Sandfish”, “Amberfish”, “White Teat”). In one of the rare cases where a species of beche-de-mer was traditionally eaten, for example on the island of Malie in the Lihir Group (by pregnant women), it has a local language name (*Puol bale*).

Perhaps the most important use of corals in coastal Melanesia is as a source of lime used for chewing with betelnut (*Areca catechu*). The combination of lime, betelnut and the fruit or leaves of *Piper betle* when chewed together produces a narcotic effect widely and frequently enjoyed throughout PNG, the Solomon Islands, and much of South and Southeast Asia. In PNG and the Solomon Islands lime can be manufactured from either coral (branching corals, typically *Acropora* spp. are preferred) or various bivalve shells. On Lihir a common term for “coral” is *Kambang*, which also happens to be the lingua franca (Tok Pisin) term for the lime that is used with betelnut.

Figure 3. Nggela boys about to burn coral for making lime (Nggela, Solomon Islands, 1995).

Do coastal Melanesians believe coral to be living or inanimate? The most common term in the lingua franca for “coral” in both PNG and Solomon Islands is *Ston* (literally: “stone”), which obviously implies that is not alive. However, people do notice that corals grow, though they mostly do not think of this growth as analogous to the growth of plants. However, many stones, including (non-coral) stones that lie underwater, are believed to possess magical qualities, and can move around, attack boats, grow or transform in various ways. Indeed the sea is full of magical, dangerous and mysterious creatures and spirits in most coastal Melanesian cosmologies (Macintyre 1983, Macintyre and Foale, in press) In PNG, people notice that corals can be “spoiled” (i.e. become covered in plant growth) if they are covered by sediment, or damaged by dynamite fishing for example. People who make lime from branching corals use only living coral branches and avoid dead ones that have algae growing on them, as the latter produce poor quality lime.

Given the relative newness of coral bleaching, and the low transmission rate of scientific information to the rural sector in PNG, it is unlikely that many rural people there will have the same interpretation of coral bleaching as western marine biologists. As yet we have relatively little data on local interpretations of coral bleaching, partly because of its recency, and partly because, on average, in most parts of Melanesia, not a lot of people dive on a regular basis. At Cape Vogel one fisherman believed coral bleaching was somehow caused by a stronger than normal Southeasterly trade wind (Jane Mogina, pers. comm.). On both Malie Island in the Lihir group, and at Tanga approximately 80km distant from Lihir, a number of people attributed coral bleaching in early 2001 to the impact of tailings from the mining operation on Niolam Island in the Lihir Group. Rotmann (2001) found bleaching at both locations to be severe, but the likelihood that it had anything to do with either submarine tailings or surface sediment runoff from the mining operation, at either site, would have been negligible (Thomas *et al.* 2003).

Local knowledge about the sea in Melanesia is a highly heterogeneous, and usually very pragmatic mix of “traditional” and western concepts. Such knowledge can also be quite individual in nature, as opposed to a “system” – this is partly because most people are secretive about their fishing knowledge, because it most often concerns where and when to find fish (Foale 1998b), which is information most fishers are reluctant to share, for obvious reasons. Explanatory models for observed natural phenomena can incorporate ecological/biophysical and magical/spiritual components. Magical processes may be used to fill in for processes that are not observed such as broadcast spawning and planktonic dispersal of larvae. Alternatively, a biological process (that may or may not fit with a western scientific model) might be hypothesised. The idea that coral is an animal in the conventional western biological sense has undoubtedly permeated into local lore in some places. The observation that coral bleaching had occurred on the island of Malie was first brought to my attention by the local catholic priest, a man who has a university education and has travelled the world extensively. He clearly knew that bleaching was harmful to the coral and was worried about it.

The following examples, from my own recent interview data on Lihir, and from field notes made by Martha Macintyre on Tubetube (Milne Bay) in 1980, should illustrate the flexible and pragmatic nature of Melanesian explanatory models about the biology of marine organisms, and the way in which they usually incorporate careful empirical observation with what people think is likely to be the most plausible hypothesis for processes which cannot be, or have not been directly observed.

1. At Lihir, in response to the stock interview question, “How do fish make babies”, a wide variety of hypotheses were volunteered. Many interviewees immediately remarked that sharks gave birth to live babies, because they had observed these in the body cavities of sharks they had caught. Most also observed the fact that fish had something in their body cavity that was glossed as “gonad”, which was sometimes enlarged and sometimes reduced in size, and that these changes in size often followed a seasonal pattern. But most remarked that they had never observed fish mating or laying eggs, and that they could therefore only guess at how they did it. Two fishers believed that fish babies came from floating logs (because juvenile fish are often observed to be lurking under and around logs floating in the sea), and were hatched from eggs that were created by the mixing of “grease” that oozed from the log, with seawater. The eggs then hatched and the baby fish stayed around the log. This model uses an analogue of the common traditional model for human reproduction, in which semen mixes with uterine blood following intercourse, and congeals to form the foetus.

2. One Lihirian man volunteered that he had sometimes seen beche-de-mer give birth to fish. This is very likely to be an observation of the Pearlfish, *Onuxodon margaritiferae* (family Carapidae), which commonly lives inside the hindgut of some species of Holothurian, and can often be seen partly emerging from the anus of its host.

3. One Tubetube man who used to dive during World War 2, for red and black coral that he sold to the soldiers, observed that these corals grew “like a tree”, but he

could not understand how, because they had no mouth, and did not excrete. He laughed as he told this story (Martha Macintyre, pers. comm.).

4. Another Tubetube man said that the Tubetube word for “alive” literally translated as “with breath”, so that if something doesn’t have breath it can’t be living. People knew fish were alive because they breathe water, and you can feel them breathing when you hold them. He said that he personally believed that trees must have “small breathing pathways, because if you cover them they die” and added “That’s just my idea” (Martha Macintyre, pers. comm.).

5. On Lihir the annual emergence of the Palolo worm (*Palola viridis*) shortly after dusk on the night after the full moon in October or November (Caspers 1984) is an occasion of great traditional ritual significance, because the animal is believed to be the creator spirit. It is harvested and eaten, as in most parts of the Pacific, but is also believed to be both auspicious and extremely dangerous. If the right rituals are not observed in association with the harvest, bad fortune is believed to be inevitable. Women and children are traditionally forbidden from contact with the worm. One woman who I spoke to about this event remarked that she had been sceptical about the alleged dangerous power of the worm, and had collected one and kept it in a glass overnight in her house, just to see if anything bad would happen to her. She recounted this story during a discussion about the biology of the worm. I had described the biological model of the Palolo worm emergence, which holds that what actually emerges (from burrows in the reef substrate) is the gamete-filled rear end (called an epitoke) of the polychaete (the head and front end remains inside the burrow). This epitoke swims out into the water column and soon disintegrates, whereupon external fertilisation takes place (the worm has separate sexes), and the fertilised eggs float off to hatch into pelagic larvae, that eventually settle back to the reef and start life as baby Palolo worms. Upon hearing this account the Lihirian woman then noted that this explained why the worm in her glass had turned into “dust” when she checked it again the following

morning. She had never understood what happened, but had “filed the information away”, and was happy that it fitted with the biological model I had presented.

6. On Tubetube a common myth described how a giant octopus would come up on the land, sit on the ground in the middle of a patch of bush, and proceed to make a garden by ripping out trees around it with its long arms. In this way it would clear a garden very quickly. When Martha Macintyre suggested that an octopus could not live on land, much less have the strength to uproot trees, her informants responded that maybe this one could, and that just because they had not seen it did mean it was not real (Martha Macintyre, pers. comm.).

These examples illustrate the individualistic and pragmatic nature of local explanatory models, and the fact that, while magic or supernatural phenomena are commonly incorporated, the models are still strongly empirically based. It also shows however that supernatural creatures and spirits are simply considered as part of the natural world for most people. The fact that the behaviour or powers of these creatures does not “fit” with every day rules of what is possible in the material world, while it might make people ponder the anomaly, does not negate their reality. The amusement (and bemusement) with which some questions are apprehended, or observations recounted, probably indicates that the subject matter is something that people don’t normally spend a lot of time thinking about, because it is not of particular importance to day-to-day survival. The foregoing evidence in my view indicates that the western model of coral biology is unlikely to be particularly problematic to Melanesian ways of thinking about marine organisms. However the complexity of coral bleaching and its causality will be significantly more difficult to communicate to rural villagers, most of whom have done no more than 6 years of primary education in the formal system. The key question at this point however, is: of what use would such communication be, even if partly or mostly successful, in mitigating damage to ecosystem services from coral bleaching?

Mitigating the damage

Clearly the most desirable solution to the accelerating coral bleaching crisis is an immediate and drastic reduction in greenhouse gas emissions. PNG is a country whose reliance on coral reef ecosystem services vastly outweighs its relative culpability regarding the future loss of those services through bleaching (Fig. 4).

Figure 4. A comparison of relative fossil fuel consumption, between Papua New Guinea (with Australia on left) and North America (right) using details from the NASA "Earthlights" image as a proxy.

In the event that emission reductions by industrial nations are slow or not forthcoming, other mitigating measures include minimising other stressors such as sedimentation, nutrient and pesticide pollution, and overfishing (Hoegh-Guldberg and Hoegh-Guldberg 2004). One commonly proposed means of achieving reductions in overfishing is the strategic positioning of no-take MPAs (West and Salm 2003). While these suggestions are clearly sensible and should be undertaken as far as possible, there exist significant problems with such an approach in the independent Melanesian states of PNG and Solomon Islands, due to the nature of customary marine tenure (Foale and Manele, in press). In terms of fisheries alone, the scale at which most fin-fish stocks are self-recruiting is likely to greatly eclipse the scale of exclusive sea territories for the majority of coastal reef-owning groups in these countries. This means that economically most people will not be advantaged by locking up all or even part of their reef in a no-take MPA, because most of the fish larvae that are spawned within their MPA will recruit elsewhere, i.e. to reefs owned by other groups and to which the original owners of the larvae are unlikely to have rights. This politically fragmented system of territoriality, enshrined in the constitutions of both countries, poses a significant obstacle to the easy and rapid implementation of no-take MPAs as both a means of enhancing fishery yields, and mitigating damage from bleaching. There are likely to be exceptions here and there, and these should obviously be taken advantage of, but another solution is clearly desirable. In the meantime, coastal Papua New Guineans will not be happy about losing their best lime-making coral to bleaching.

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Appendix 1. Selected hits from a Google search for "coral bleaching" and New Guinea" (in February 2004).

http://zircon.geology.union.edu/Carb/bleach:

The following was sent from John Rewald, Motupore Research Station in Papua New Guinea (07-MAR-96):

A significant area from South of Normanby Island through Cape Vogel, and to Tufi is suffering from coral bleaching over the past 3 weeks, extending down to 20 metres. Bleaching in shallow water is most extensive - almost 100% in some areas, including soft corals and anemones. Water temps have been 29 to 30 deg. C during DEC for past 2 months. This is the longest recalled period of warm water in Milne Bay province - weather also calm and skies relatively clear. Reefs North of Normanby/Fergusson islands are not affected to any degree though signs are there. Corals appear live at the moment with patches of dead coral and beginning of algal growth. I will be monitoring bleaching over next 5 weeks.

These are observations from Bob Halstead, operator of dive boat Telita and he requests advice from scientists as to what he should observe. Please contact Rewald on jrewald@peg.apc.org

http://www.blue-oceans.com/scuba/coral_bleaching/png.html:

When the sea temperature in PNG's famous dive spot, Kimbe Bay, reached 32 degrees C in March, Max Benjamin knew the corals would bleach. The President of the PNG Divers Association was right. Before long, he observed at least 10 per cent of corals bleaching on many of the area's reefs. Mr Benjamin is concerned about the increasing incidence of coral bleaching in PNG. "In the last four years there has been a lot of stress on the reefs," he said. There was a bleaching event in 1996, then in 1997 a drought and high winds affected the reefs. In the summer of 1999 bleaching affected around 10 percent of corals. Now, it's happened again in 2000. "The reefs look OK, but it's nibbling away at them every year," he said. "It's beyond our control - we just sit and hope that the temperature will drop."

http://www.sbg.ac.at/ipk/avstudio/pierofun/png/png4.htm

Coral bleaching: This has been observed in PNG during three main periods over the past 20 years. The most severe and widespread bleaching event in PNG appears to have occurred during 1996-1997. Milne Bay was the most affected area with one study reporting 54% of corals exhibiting bleaching. Most other areas had lower level of bleaching and good recovery has been reported in most areas indicating that this bleaching event was short enough to prevent large scale death in affected colonies. On average, none of the bleaching events in PNG appear to have been as severe as those reported from some other countries. Bleaching has again been observed in several locations during early 2000. With the apparent increase in the frequency of bleaching events in PNG over the past few years, it is important that coral bleaching and associated physical parameters (particularly sea temperature) be monitored in a coordinated manner.

http://www.osdpd.noaa.gov/PSB/EPS/SST/data/als_bleaching.4.19.1999

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Date: Mon, 19 Apr 1999 08:50:38 +1000
From: Norman Quinn <quinnnj@upng.ac.pg>
Subject: bleaching in PNG

...from our surveys this weekend around Port Moresby
we now observed at ~10m up to 60% of the coral bleached on lagoonal
reefs and 35% bleached on outer barrier reefs. soft corals more likely
to be bleached than hard corals at both sites. Only about 5% of the
bleached corals totally bleached, but we are looking at an event in
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progress. Most of the bleaching occurred on the tops of corals. No sponges bleached. Bleaching observed to 30m on the outer reefs although at that depth fewer corals are bleached and none totally bleached. Reports from New Britain saying bleaching occurring there too.

After several years of severe drought this has been the wettest "wet" in 20 years - so the locals say. No major deluges, just steady pm showers on the coast and heavy clouds in the mtns. I am trying to track down Met Office rain data.
While the water temp has increased we have had lots of cloud and very few hot sunny days. The wet started early in late Oct and has continued.
It normally ends several weeks before Easter. There are no signs that the rains are diminishing.

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http://www.aims.gov.au/pages/research/coral-bleaching/1997-98-mbe/mbe-08.html

Papua New Guinea

Water temperatures below 10 m around Kimbe Bay (New Britain) in August 1998 were 31-31.5°C, and on the surface they were 32-33 °C. High mortality of corals was observed with 75% of *Acropora* affected, and bleaching in many other genera including *Porites*, *Platygyra* and

Montipora. Some others were partially bleached, and effects were observed down to 50 m. On the southwest side of Kimbe Bay, water was 29.5 to 30°C, and there was only 10% bleaching of *Acropora* and only isolated cases of bleaching on other species.

In March 1998, large areas of reefs south of Normanby Island through to Cape Vogel, and Tufi (far southeast PNG) showed coral bleaching from mid-February. Bleaching extended down to 20 m, but was most extensive in shallow water (almost 100% in some areas, including soft corals and anemones). Water temperatures were 29-30°C from December to February, which is not exceptional for Milne Bay. Reefs to the north Normanby and Fergusson Ids were apparently not affected by any bleaching.

(James Cervino, John Rewald)