An historical overview of impacts from land-based pollution on community based natural resource management (CBNRM) as it applies to marine fisheries & coral reefs in the tropics.

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Abstract

The purpose of this review is to provide an historic record of the author's experience from the 1960s through the 1990s with coral reefs and the impacts of land-based pollution and other actions by man on this important ecosystem, from the islands of the Caribbean and Central America to the West/East Coasts of Africa and the Western Indian Ocean. This is tied into the concept of Community Based Natural Resource Management (CBNRM), its origins in Southern Africa tied to Africa's mega-fauna and how it can apply to fisher communities in the tropics. It concludes that unless human population pressures and the current forms of "development and conservation" both linked to pollution and habitat degradation are addressed, the future for both man and these unique ecosystems are in jeopardy. A key to this solution is how the Developed World relates to the Developing World. It is hoped that this review will provide insight to future generations of ecologists, researchers, resource managers, politicians donors and NGOs (non-governmental organizations) as to the issues they will confront if both mankind and nature are to have a viable future, living in harmony. Currently, they appear to be in conflict with each other and only man can resolve these issues based upon how he interacts with Mother Nature.

Keywords: CBNRM, Coral reefs, Traditional resource users, Fishers, Traditional knowledge, Land-based pollution, Ocean warming, Coral bleaching.

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Origins of Community Based Natural Resource Management (CBNRM)

The Community Based Natural Resource Management (CBNRM) concept became popular in the mid-to-late 1970s beginning with Zimbabwe's development of the Communal Areas Management Program for Indigenous Resources (CAMPFIRE), spreading through Southern Africa and eventually the globe. Traditionally, CBNRM was initiated in areas outside the park estate, co-habited by humans and wildlife bordering parks or in game reserves, designated as hunting blocks as a means of conserving Africa's mega-fauna and their habitat [1]. The idea was to integrate the needs of impoverished subsistence-living rural communities into the management of these peripheral areas.

The Driving Force behind CBNRM is "Adaptive Management" as Opposed to the "Precautionary Principle" [2]

Western scientists and researchers, especially in East Africa have tended to dominate conservation using the "precautionary principle". The protectionist approach of the precautionary principle (founded in Western urban industrialized settings where humans have lost their dependency on surviving directly off the environment) purports that wildlife and its complex life cycle must be fully understood before it can be used and that this requires time and extensive research. What this means, in essence, is passive management of the species, allowing "natural regulation" to dominate as the management approach, which assumes that nature will take care of itself. The best examples of this can be found in Uganda and Kenya, where American and British-based animal rights groups, and Western researchers with no management skills have applied an anti-sustainable use policy.

The adaptive management approach relies on a crude evaluation of wildlife resources based on available data on a specific species in order to make conservative estimates of sustainable off-take. This off-take is monitored while data gaps are identified and filled to help make better management decisions on how to best utilize wildlife as an economic and rural development tool for Africa. Adaptive management is the basic tenet of Southern Africa's approach to sustainable use. It is a pre-requisite for CBNRM to begin, since poverty, despair, alienation and disenfranchisement will not wait for Western scientists to study wildlife and its habitat to the detriment of the people and their resources. If a mistake is made in over-harvesting wildlife, most wildlife populations, including elephant, can recover in ten years, while once the habitat is destroyed, it can take 100s of years for the vegetation and 1000s of years for the soil to recover. Thus, preferences for non-consumptive uses and intangible uses that appear to be anthropogenic philosophical desires not to interfere with nature rather than any understanding of how an ecosystem functions, are often more consumptive than what is currently termed consumptive use. Thus, ecosystem management becomes more important than single species management, and the adaptive management concept allows for quick recovery if mistakes are made, much quicker than the precautionary principle espoused by the Western animal rights movement and researchers who would prefer to take no action, or study wildlife and ecosystems to extinction and/or irrecoverable ecological degradation.

Major problems still being addressed include [1,2]

- Creation of parks and protected areas, exclusion zones for the local communities based upon the classical "fortress conservation" or the "fence and fines" approach.
- Lack of transparency and misuse of revenue destined for the rural communities by local governments and community elites,
- Majority of revenue captured by stakeholders other than the rural communities including directly by central/local governments and safari/tour operators, as well as,
- Indirectly by non-governmental organizations (NGOs) absorbing huge quantities of donor funds with very little reaching the rural communities, in both cases what some call a form of neo-colonialism, where donor driven CBNRM programs tend to reward rural Africans for the loss of access to their resources, primarily in hunting blocks, by providing them with material compensation for foregoing traditional ties to wildlife and other resources; "communities do not have the right to use wildlife, only the right to benefit from the use of wildlife by others",
- With few exceptions the resource to human population ratios are so low that benefits at the household level are insignificant resulting in most of the revenue reaching rural communities, which is not squandered by the local elites, being used for common property benefits such as schools, boreholes and clinics,
- Being based primarily on revenue from hunting, ignoring the possibility of sustainable multiple use conservation of other natural resources such as fish, timber for construction/firewood/charcoal, thatch grass, wild medicines, minerals, etc.
- Thus, a failure to integrate traditional natural resource users (e.g. hunters, pit sawyers, fishers. healers, herders, etc.) into the management of these areas, cutting them off from the very resources that provide important sources of income at the household level and in many cases having strong religious and cultural ties.

People living subsistence lifestyles that depend upon access to natural resources to feed and provide income to their families have a difficult time buying into "conservation" programs imposed upon them by governments and NGOs that cut them off from accessing these resources. In fact, this can result in just the opposite, uncontrolled poaching from bush meat to rhino horn and elephant ivory, etc. where corrupt middlemen capture the majority of value from the natural resources as opposed to the people living with the wildlife/natural resources. This makes conservation tied to the concept of sustainable use impossible as resources tend to be mined rather than managed. In South Africa, abalone poachers are so desperate to earn a living; the divers swim more than 3 km to Dyer Island and back again, crossing a deep channel where sharks hunt for prey. They can earn as much as 10 and 15 kg of abalone per diver — equal to at least R 4,000 (about US$ 275) each per trip, but many have died from shark attacks or drowned [3]. The CBNRM concept, if applied would diminish such risks allow these fishers to earn an honest livelihood and assure conservation of the abalone.

CBNRM, Coral Reefs & Fisheries Management in the Tropics

Efforts are underway in many parts of the world to integrate fisher communities into coastal zone management to mitigate adverse impacts from unmanaged fishing, such as community managed no-take fishery reserves [4-12]. Tanzania is one of the leaders in this effort [13-16].

Fishermen, Victims of Land-Based Pollution

With regards to CBNRM and marine fisheries, fishermen are often victims of land-based pollution that results in nutrient/sediment pollution from sewage and gray water associated with tourism, as well as runoff from agricultural lands with the net result of corals being smothered by epiphytic algae and sediment; and pesticides from agricultural runoff [2,14,17]. Once the habitat is degraded, the fishery is degraded, adversely impacting the lives of fishing communities that have thrived for generations on what were once pristine ecosystems. This is primarily an issue with reef-building (hermatypic) corals that depends on the symbiotic relationship between coral polyps and unicellular algae called zooxanthellae (Figures 1 and 2). Zooxanthellae are symbiotic dinoflagellate algae living within the coral polyp providing its coral color and food from photosynthesizing. Zooxanthellae provide oxygen and recycle phosphates and nitrates from the coral's waste products, enabling an entire ecosystem to develop in unproductive, nutrient poor water. Efficient and rapid recycling of these nutrients results in the tropical world's coral reefs being one of the most productive

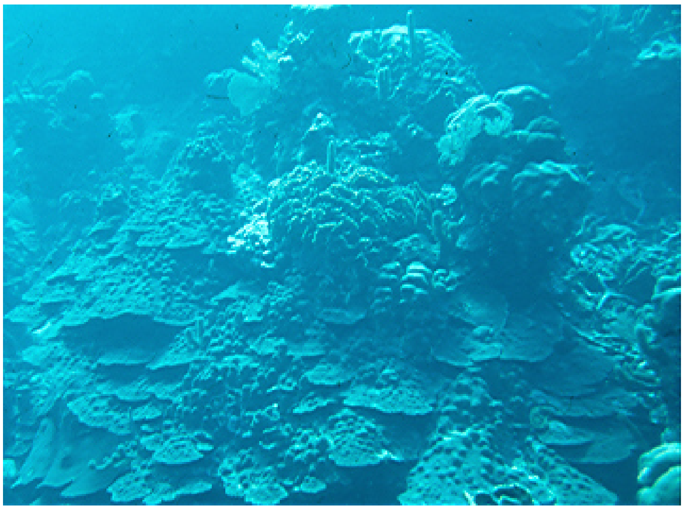

Figure 1. *Structurally sound coral reef at 30 m. depth, Roatan, Honduras, 1977. These reefs were coral dominated while algae were a minor component of this ecosystem [2,14].*

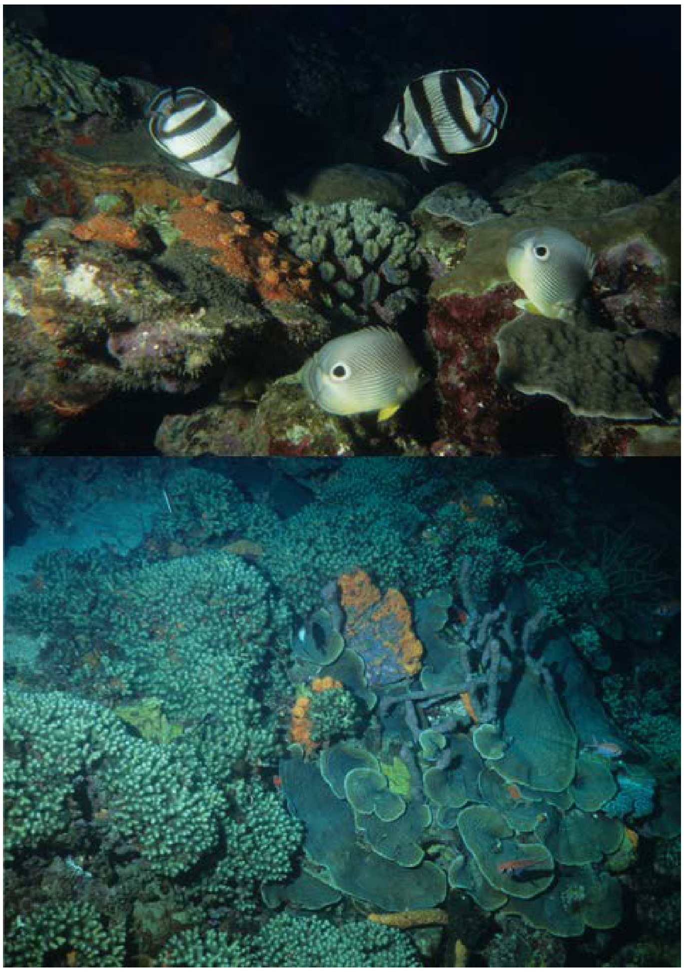

Figure 2. *Healthy coral, outer bank reef at depth of 20 m (65 ft.), West Coast, Barbados, 1988/89 (Top) & Questrelles Point, St. Vincents, 1989 (Bottom). Photo taken by DeGeorges & Reilly [2].*

natural and diverse communities, marine or terrestrial. Approximately 94-98% of all organic carbon produced by the zooxanthellae during photosynthesis leaks out of the algal cells to be used as a food source by the coral polyp. The production of carbon greatly increases the rate of reef building by increasing the rate of deposition of the corals' limestone skeleton (CaCO3). This light enhanced rate of calcification enables the coral reefs to grow faster than they are eroded by the action of the sea and eroding organisms (e.g., parrotfish, boring sponges). It is the major reason why light and thus depth are limiting factors to colonial corals (Figures 1 and 2).

This is not an issue for corals without zooxanthellae, called ahermatypic corals that are not limited by light, and which grow at great depths and are mostly small, solitary, and slow growing. But they can form large colonies in deep or cold waters, for example in the Gorgonian soft corals shown from Cap Verte Peninsula, Dakar, Senegal, in West Africa (Figure 3).

Nutrient Pollution & the Demise of Coral Reefs

Excessive nutrient concentrations from pollution can lead to demise of the hermatypic coral reef community as the result of phytoplankton blooms, decreased light penetration and photosynthesis of zooxanthellae, thus reducing coral productivity. Reduced light penetration from algal blooms and coastal sedimentation also reduces photosynthesis of sea grass beds, causing their demise. But the greatest impact of high nutrients comes from benthic macro-algae (epiphytic) blooms that directly smother and kill corals; a competition with hard corals which they have lost. Thus, there can be a change in community structure from a hard coral dominated to an algal-dominated system [2]. Thus, the habitat for the fisheries is degraded if not destroyed (Figure 4).

Recommended water quality standards to protect hermatypic coral reefs from nutrient pollution and common macro-algae impacting coral reefs when these standards are exceeded can be found in DeGeorges, et al. [14] (Figure 4).

Observations of Coral Reef Quality in the Caribbean

Observations by the author are contained in the Table 1. The importance of traditional knowledge by fishers in understanding what is causing the demise of a coral reef or fishery cannot be over-emphasized [18]. In the case of Belize (See observations by fishermen in Table 1), this insight was critical, where the

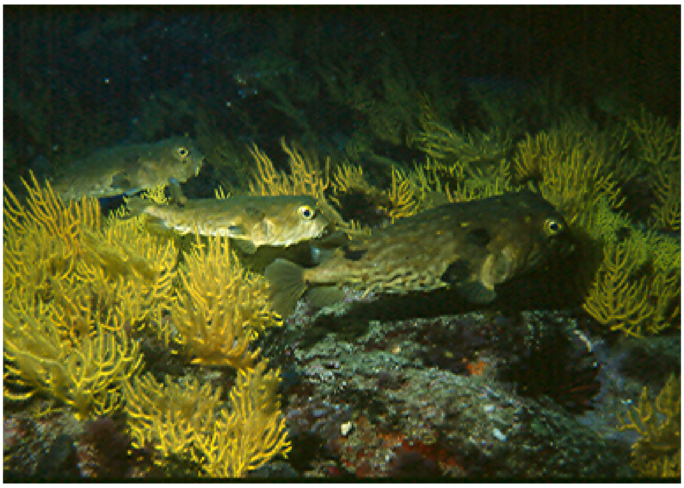

Figure 3. *Typical ahermatypic Gorgonian soft corals, Cap Verte Peninsula, Senegal, 1984. Photo taken by DeGeorges et al. in 1984 [14].*

Figure 4. *Porites porites "finger coral" being smothered by macro-algae, Dictyota sp., from inappropriate septic tanks, Grand Anse Beach Grenada, 1988. Similar patterns are seen around densely populated coastal areas and tourism areas worldwide [2,14].*

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Table 1. *Typical sewage treatment systems and impacts on coral reefs observed by principal author in the Caribbean (1989-1990).*

Location	Sewage Treatment Level	Observed Ecological Impacts
BARBADOS -Bridgetown	-Activated sludge	-Major odor problems, short outfall degrading surrounding environment.
-West and South Coast (major tourism areas)	-Hotels on septic systems or package plants with short outfalls Note: Deep water outfall planned for Bridgetown and West Coast	-Fringing reefs 99% dead, outer bank reefs beginning to show signs of algal overgrowth, near shore fishing on a decline, beach erosion accelerating. -Reef mostly dead from inappropriate sewage and apparently high sedimentation associated with steep-sloped agriculture. -Barbados reefs are eutrophic, but because there is high parrotfish grazing the algae are made of short turfs rather than fleshy macrophytes, but the dead coral is still algae covered.
GRENADA		
-St. Georges	-Raw sewage outfall.	-Did not dive area, but outfall appeared too short in relation to currents, risking to contaminate near shore waters – 400 m outfall – real question is degree of offshore currents in region of outfall to dilute and carry pollution out to sea
-Grand Anse Bay	-Three tourist hotels on septic systems, Medical school on septic system. Private homes?	-High incidence of eye, ear and skin infections & High percentage of the *Porites* sp. coral dead and overgrown with *Dictyota* sp. algae
TOBAGO KEYS, THE GRENADINES: Horseshoe and World's End Reefs	-Up to 140 boats a day anchors in the vicinity of these reefs during the winter months, none of which have holding tanks. -Additional pollution is believed to come from inappropriate sewage disposal on the islands of Petite St. Vincent, Petite Martinique, Union, Mayreau, Canouan and Palm.	-Approximately 99% of the elkhorn coral (*Acropora palmata*) dead but still standing -Approximately 30-40% of *Porites* sp. Dead -Overall state of reef degraded, much of dead coral covered in light purple coralline algae
ST VINCENT Young Island and the Bay lying between Young Island and Dike Island	-Hotels on septic systems -Large number of sail boats with no holding tanks	-Coral reef around Young Island and mainland hotels mostly dead -Large areas of dead elkhorn and *Porites* sp. Elkhorn alive in the early 1980s
Kingstown	Central collection system pumping raw sewage into Kingstown Harbor	Between Harbor and Camden Industrial Park: -Old Woman Point. Shallow star coral shows signs of bleaching. Deeper portions of reef - star and other coral in reasonable condition -Turtle Bay most of reef algal covered -Coral Garden near industrial park, mostly dead algal-covered *Porites* sp. -Questelles Point just north of industrial park, most of coral appears healthy, lots of deep water star coral, *Montastre annularis*
ST. LUCIA		
Castries	-Sewage collection, preliminary treatment dumped into harbor	-Water quality and marine benthos study by Caribbean Health Institute showed area to be very eutrophic.
Anse Chastinet, Pitons Area	-Hotel on septic system -Town? Septic systems	-Some of best reef in the Windward Islands. -Watershed a protected rainforest – low human population
DOMINICA Roseau	-Up to ten raw sewage outfalls	-Dangleben's Reef. Shallower than 30 feet coral smothered in *Dictyota sp.* algae. Below 40 feet depth, algae cover falls off and living coral becomes more dominant. -La Bim wall covered in silt
Small Coastal Villages	-Community pit latrines right on the edge of the sea	-Hot Springs area covered in *Dictyota sp.* Algae
Other	-Many people dump chamber pots into streams.	-Scottshead area some good reef, but heavily algal covered -Point Des Fou reef walls nice but coral heavily covered in algae
ANTIGUA	Becoming heavily built out for tourism, hotels on septic systems or package plants.	-British Armed Forces divers as part of Reef Watch warn Antigua government that its reefs are rapidly degrading from sewage and sedimentation. -Shallow offshore reefs on high-energy zone at Ariadne Shoals and Soft Willie appear degraded.

ST. KITTS		
Basseterre	-No sewage or collection system, sewage flushed into Basseterre Harbor during rain events	-USAID sponsored Southeast Peninsula environmental study found that most of the reefs south of Basseterre were degraded and algal covered.
Sugar Cane Refinery	-Dumps untreated waste into Basseterre Harbor	
Frigate Bay Hotels	-Package treatment plants into lagoons, one discharging into Atlantic and the other to the Caribbean side, newer hotels treatment discharge unknown	
U.S. VIRGIN ISLANDS	Secondary treatment and septic systems?	Personal communication between the author and natural resources planner from islands associated with Ed Towle of Island Resources Foundation, leads the author to believe that there is heavy coral reef degradation.
HAITI		
Port Au Prince	No known treatment systems! Raw sewage direct or through groundwater seepage	Les Arcadins Marine Park contains severely degraded coral smothered by *Dictyota* sp. algae.
DOMINICAN REPUBLIC		
La Caleta by airport	Unknown	Coral reef appears healthy.
HAITI		
Port Au Prince	No known treatment systems! Raw sewage direct or through groundwater seepage	Les Arcadins Marine Park contains severely degraded coral smothered by *Dictyota* sp. algae.
JAMAICA **Montego Bay**		
Note: Deepwater outfall planned?	-Trickling filter plant is being bypassed dumping 3.0 million gallons/day of raw sewage into Montego River 200 m upstream from where it enters Montego Bay -Some hotels on septic systems and package plants -Two major rivers with small-scale farmers using inappropriate soil conservation resulting in heavy siltation	Coral reef over the entire bay is mostly dead and algal/silt covered.
BELIZE **Belize City**	-Oxidation ponds with near shore outfall	-Coral reefs dived by author along Belize's 240-250 km barrier reef appear to be highly degraded and have high algal cover.
Ambergris Cay, Holchan Marine Park	-Septic tanks at most hotels	
Caye Caulker	Four-inch raw sewage outfalls	-This includes the outer atolls such as Lighthouse and Blue Hole, though they are less degraded than the barrier reef along two Cayes.
Placencia	-Fishing village, maybe one resort?	
Lighthouse Reef and Blue Hole	-No sewage, Virtually undeveloped	-Obvious other factors coming into play, but sewage believed to be major cause of degradation. -In vicinity of Ambergris Cay and Cay Caulker, annual production of sewage equivalent of dumping 6,500 fifty-pound sacks of 20/10/10 (N/P/K) fertilizer onto barrier reef.
Observed Ecological Impacts (cont.):	Observed Ecological Impacts (cont.)	
-Other possible causes linked to land-based pollution, noted by local fishermen are rivers & streams that now run dirty from watershed degradation linked to U.S. citrus companies, and refugees practicing slash and burn agriculture in Belize. Fishermen also claim that "dirty" water from the deforested Gulf of Honduras flows over the reef during the rainy season. -Reef off Placencia – maybe 1-2 km offshore heavy epiphytic algae cover	-Cay Caulker (cont.): In the shallow backwater areas, boulder coral (mountainous star coral) alive along the edges but smothered with algae on the top similar to Mexican Rock at Ambergris Cay. -Fishermen claim that in the late 1970s a hurricane hit and a fertilizer ship ran aground on Lighthouse Reef. Fertilizer never removed, and a freak red tide killed off many of the fish that are algal grazers, especially parrotfish whose populations have never recovered. These events could be linked and need further investigation.	-Cay Caulker: structurally intact dead Elkhorn corals, *Acropora palmata*, at the very top of the barrier reef. In the cut, large areas of massive leaf coral, *Agaricia agaricites* var. *da*nai, smothered in algae. Dead Elkhorn coral covered in coralline algae also seen intact at depths of 15 ft.
Observations by DeGeorges in the late 1988-1990, while USAID's Regional Environmental Management Specialist for the Caribbean, (REMS/C), in DeGeorges & Reilly [2]		

virgin coral reefs the author had dived upon as a Peace Corps Volunteer in the mid-1970s, had turned into algal-covered reefs by the late 1980s:

"However, fishermen agreed that where the "rock" (that is coral) died, the lobster left. As one fisherman put it, "when the lobster's house gets dirty he leaves". Many fishermen began observing changes in the structure of the coral community, some placing these at seven to eight years earlier (1981/1982) while others estimated that changes started taking place four to six years earlier (1983-1985). The change observed by the fishermen was an increase in algal cover locally known as morasse and a gradual dieback of the Elkhorn coral (Acropora palmata), known locally as pantia or moose coral. They said that when the Elkhorn coral dies, the lobster does not come back! This could have been from a combination of the "white band" disease that is known to have killed Acropora spp. and pollution resulting in high algal cover" [2,19].

Underwater Observations & Pollution in the Western Indian Ocean in the 1990s

The following observations by the author are contained in

Tables 2 and 3:

Estimates of pollutants from municipal wastewater in the Western Indian Ocean are contained in Table 4.

Industrial effluents appear to be primarily oxygen-consuming organic materials as measured by Biological Oxygen Demand (BOD) from agro-industries in Western Indian Ocean countries (Table 5).

Top-Downers, Blaming the Fishermen versus Bottom-Uppers Blaming Pollution for Demise of Coral Reefs

There are major debates as to which is more important to the demise of coral reefs, land-based pollution (“Bottom-Uppers”) or over-fishing ("Top-Downers"). Many coral reef biologists believe overfishing of herbivores is of greater importance than nutrients in driving algae overgrowth of reefs, though most publications supporting this “top-down” hypothesis lack nutrient water quality data. “Top-Downers” suggest the solution is to stop fishing. If this were the limiting factor in reefs, herbivorous fish populations would crash as fisheries intensified, causing reef algae to proliferate, so preventing fishing should cause corals and fish to recover. But in fact, these patterns were not seen in the Caribbean: overfishing long preceded coastal tourism over-development, while sewage effluents and algae proliferation increased simultaneously whenever new tourism areas were developed, and fish populations changed from being carnivore dominated (the preferred choice of fishermen) to becoming almost entirely herbivore dominated as algae became the only abundant food source. It has been found that a reduction in herbivory from overfishing may enhance the likelihood of

Table 2. *Underwater survey observations, Mahé & St Anne marine park, the Seychelles, 1990.*

Site & Site Number On Map	% Live Coral	% Dead Coral	% Silt	% Algal Cover	Prevalent Algal Species
1990					
Baie Ternay National Park, near lighthouse	100	0	0	0	-
Baie Ternay National Park, 1 km off of National Youth Service camp,	70-80	20-30	0	0	-
Auberge Club De Seychelles 100 m off shore	95	5	0	0	-
1 km offshore from Victoria Sewage Treatment Plant, in vicinity of outfall	5	95	Minimal, Colloids in water column	95	*Sargassum* spp.
Brilliant Point, off lagoon outlet, just off of and before Runway Lights	10-15	85-90	40	40	*Sargassum* spp.
Ile Cachée, St. Anne National Marine Park	70	30	0	≤ 30	*Turbinaria* spp.
Ile Moyenne, St. Anne Channel	≥ 95	≤ 5	0	≤ 5	Shallows (≤ 5 ft) dominated by *Turbinaria* spp.
Methodology: Line Transect Method. Principal author laid out five randomly placed 15 m transects per site, 1/2 m^2 quadrat laid down every three meters along marked chain and percent/live dead coral estimated and recorded on an underwater slate. The percent live/dead coral averaged for each site. Underwater video also made and viewed to verify underwater observations [14]					

Table 3. *Other observations in the Western Indian Ocean, 1990-1997*

SITE	CORAL REEF QUALITY	POSSIBLE CAUSES FOR CORAL DEGRADATION
Stone Town, Zanzibar 1990	99% Live Coral	1 km offshore fringing island. Reef near port & new tourism hotels shows signs of algal cover
Kilifi, Kenya, in front of sisal plant, 1991	99% Dead Coral	Coral reefs below sisal plant discharge dead & smothered in sediment from directly discharged plant effluent,
3 km up coast from Kilifi sisal plant	99% Live Coral	Low density tourism homes – corals healthy, though at low tide, local fishermen walk on shallower coral reef to catch fish
Diego Suarez, Madagascar, Off Military Base 1991	99% Live Coral	Very little development in the watershed
Ile De Maurice (Mauritius) Grand Baie Aquarium October 21, 1990, NW/N Coast	95-98% Dead Coral & Covered with Macro-Algae	Coastal Watershed covered with tourist hotels, and no or improper sewage treatment & disposal. Inland watershed covered in sugar cane and some tea with one of the highest rates of pesticide application/km^2 anywhere in the world.
Big T and Fern Reefs, 45 min up coast from Dar es Salaam, Tanzania, off Sea Breeze Hotel, December 1997. 5 Dives	99% Live Coral	Low volume development in watershed with a few hotels
Pemba, Mozambique, March/April and December 1998, four dives off Nautilus Hotel	50-70% macro-algae covered coral reefs	Pemba has human population of 88,000 & no sewage. People defecate on the beach; the case all along the coast of Cabo Delgado Province.
Baixo Danae (Shallow Place) 1990, 50 km (31 mi.) off of Maputo and 10 km (6.2 mi.) N/NW off Inhaca Island, 1990	40% Live Coral	Physically damaged, possibly from dynamite fishing or trawlers dragging nets
Inhaca Island, off Maputo, Mozambique, 1990	60-80% Dead Coral	Visibility low, high algal cover on reefs – signs of pollution from capital city & refugee camps on Inhaca
Methodology: DeGeorges swims randomly over reef recording overall impressions. The uniqueness of this data is that one person (important as a means of providing reasonable precision) had the opportunity to make observations of coral reef quality over a large area of the Western Indian Ocean just before the 1998 ocean warming event [14].		

Table 4. *Representative estimated loads pollutants & volumes of municipal wastewater into coastal areas of the Western Indian Ocean.*

	Estimated Loads (tonnes/year)				
Country	**BOD (1)**	**Suspended Solids**	**Nitrogen (2)**	**Phosphorous (2)**	**Estimated volume of municipal wastewater (m^3/day)**
Comoros	489	1,063	212	26	168
Kenya	2,744	3,889	802	97	145,500
Madagascar	2,962	6,869	1,417	172	
Mauritius	598	1,388	286	35	130,420 (173,500 after extension of system)
Mozambique	1,137	1,203	108	26	29,149
Seychelles	541	1,254	259	31	4,922 (10,372 after extension of system)
South Africa	39,502	30,478	4,518	2,259	255,000 (offshore, 1° treatment) 46,300 (surf zone, 2° treatment) 31,500 (estuaries, 2° treatment)
Tanzania	21,741	50,413	10,398	1,260	37,912

(1) Biological Oxygen Demand (BOD) is a measure of oxygen depleting organic material
(2) Not indicated in which form estimate is made (e.g. as P or $P0_4$, N or $N0_3$)
Source: UNEP/WIOMSA [20], in DeGeorges et al. [14]

Table 5*. Industrial pollutants, western Indian Ocean.*

Country/Source	**Source of Pollution**	**Pollutants**					
		BOD	**Suspended Solids**	**Solid Waste**	**Nitrogen**	**Total P**	**Heavy Metals**
Comoros UNEP/WIOMSA [20]	Agro- industries	Significant, small compared to domestic waste	Same as BOD	-	-	-	-
Kenya UNEP/ WIOMSA 2009 [20]	Cashew nut and sisal processing	High from sisal wastes	High from sisal wastes	15,330 & 8,400 tonnes/yr. respectively	-	-	
Mauritius UNEP/ WIOMSA [21] Ahamada et al. [21]	31 industries Agricultural Runoff	1,117 tonnes/yr. -	2,306 tonnes/yr. -	- -	17 tonnes/yr. Coral reefs degraded by sediment & nutrients	81 tonnes/yr. -	- -
Mozambique UNEP/WIOMSA [20]	137 Industries around Maputo, Matola & Beira: textile, paper, tyre, brewery; discharging untreated wastewater	79,388/yr. in 1996	-	-	-	-	Unquantified heavy metals
Seychelles	Agro-industries	17.7% of total	6.7% of total	-	-	-	
Zanzibar, Tanzania UNEP/WIOMSA [20]	Food processing (slaughter houses, dairy, beverages) & soap) Various industries in Stone Town.	15 tonnes/yr. -	16 tonnes/yr. -	- -	- -	- -	- Significant levels of aluminium & cadmium in macroalgae from Chapwani & Changuu Islands off Zanzibar

Abbreviations: BOD: Biological Oxygen Demand, Total P: Total Phosphorus as P
Source: in DeGeorges et al. [14]

inorganic/organic pollution causing a coral-algal phase shift, but a reduction in herbivory in the absence of eutrophication can also lead to the proliferation of algae [14].

While the debate continues, if land-based pollution and over-fishing are not addressed, the creation of marine parks will not save the coral reefs nor the fisheries, and any hope of expanding the concept of CBNRM to coastal fisheries will be lost.

Coral Bleaching

Until massive coral bleaching and die-off due to recent ocean warming events starting in the 1980s, a major cause of coral die-off globally had been and continues to be nutrient pollution. Coral bleaching is the whitening of corals that occurs when the zooxanthellae are lost from coral tissues or the amount of photosynthetic pigment in the zooxanthellae is sharply decreased. Because corals can only survive in a limited range of conditions, a slight temperature increase over a prolonged period can result in bleaching. Stresses from pollution (e.g. nutrients, sedimentation), high levels of light, infections, excess shade and fluctuations in salinity levels are also associated with incidents of coral bleaching. If the sea surface temperature (SST) increased 1°C for a month or longer above the long-term average for the warmest months/season, the period was termed “a hot spot” and usually resulted in mass bleaching of coral reefs. If these conditions last only one month and it then cools down, almost all corals will gradually recover. If excessively hot surface water conditions persist for two to three months or if surface water temperatures reach 2°C or 3°C above average for one month, coral mortality becomes significant. In the Caribbean, once seawater temperatures reach about 30°C for a few weeks, corals can begin experiencing “bleaching”, the degree of bleaching appearing to increase with the length of period of elevated surface water temperatures. In 1982-1983, 70-95% of the corals in the Eastern Pacific off of Costa Rica, Panama, Colombia, and the Galápagos Islands died because of bleaching caused by the warm waters brought by El Niño (ENSO - El Niño–Southern Oscillation, irregularly periodic variation in winds and sea surface temperatures over the tropical eastern Pacific Ocean). In the late 1980s and early 1990s, bleaching became a regular and pervasive problem in the Caribbean and began to appear in the Pacific and Indian Oceans -- often related to El Niño events. During the El Niño of 1997-1998, bleaching began in the eastern Pacific but then expanded to an unprecedented, alarmingly broad region across the Indian Ocean from Kenya to Indonesia and in the Pacific Ocean from Australia to Polynesia [2].

The consequences of coral die-off, be it from land-based pollution or ocean warming are similar; dead reefs, increased beach erosion, decreased fishery habitat, public health issues, declining tourism and ultimate loss of key economic sectors. One might challenge the importance of land-based pollution when the consequences of ocean warming events on coral die-off were as much as 10 times that from other causes in the Seychelles and much of the Western Indian Ocean (e.g. sediment from land or dredging, algae overgrowth, tourist and anchor damage, storm waves, or coral-eating crown of thorns starfish), resulting in 75-99% loss of live coral. However, corals have begun recovering from this ocean warming event. Recovery can be enhanced by diminishing stresses like land-based pollution. Ocean warming must be dealt with through long-term international negotiations, but land-based pollution can be dealt with immediately at regional and local levels [14] (Figure 5).

The following summarizes the author's experiences in the Caribbean and how they relate to the Indian Ocean along the eastern side of the African continent in the development of coastal tourism. General conclusions drawn are [2]

• Land-based pollution is a primary cause of coral reef degradation. At the September 1988 Regional Seas Conference sponsored by UNEP in Mexico City, land-based pollution was considered the number one environmental problem affecting the Caribbean Basin;

• This is primarily from nutrient enrichment of near shore marine waters associated with improperly or untreated domestic sewage and gray water originating from major urban areas and from tourism developments;

• The world's tropical waters are nutrient poor and ecologically thrown out of balance by this enrichment, resulting in coral reef ecosystems collapsing as a result of being smothered by epiphytic algae (benthic macro-algae), which prevents zooxanthellae (a symbiotic dinoflagellate living within the coral polyp from photosynthesizing (gives coral color & provides colonial corals with 98% of their total food requirements), the rest of its food coming from the polyps filtering micro-organisms out of the water – thus cutting off the coral's food supply and starving it to death;

• Believed to be secondary in importance in causing coastal degradation are pollutants associated with agricultural runoff including sediment, pesticides and fertilizers, often from ill-conceived donor policies (e.g. subsidized bananas in the

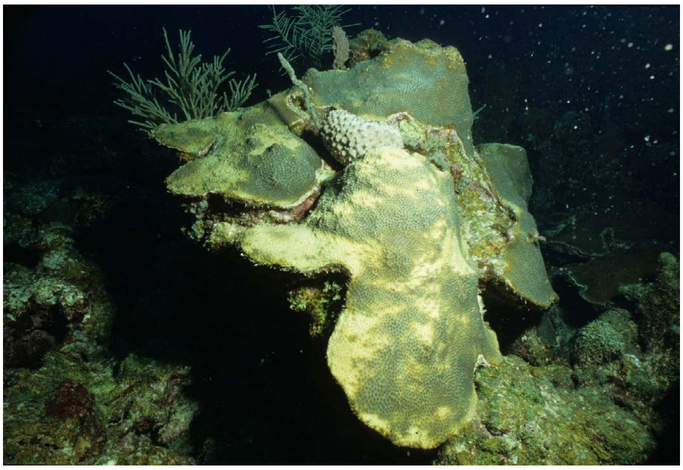

Figure 5. *Coral bleaching, West Coast, Barbados, 1988/1989; zooxanthellae giving, coral color, have been extruded, but coral is still alive [2].*

Caribbean on many of the "banana islands" such as Grenada, St. Lucia, St. Vincent and Dominica) (Table 6);

• The loss of coral reef from sewage/nutrient pollution sets off a cycle of beach erosion as the source of sand, (corals breaking down gradually over time provide a major source of sand along with coralline algae) and because of lost protection from wave and storm action by the collapsing reef. This, along with declining artisanal fisheries from habitat loss and eye, ear and skin infections of bathers/swimmers, has the net result of diminishing tourism attractions;

• Western waste treatment technologies solve neither ecological (e.g. up to secondary treatment removes primarily biological oxygen demand/BOD but few nutrients) nor public health needs (e.g. secondary treatment as commonly used with relatively short outfalls.

• High tech tertiary treatment that removes significant amounts of nutrients suffers along with secondary treatment from high operation and maintenance levels (cost of maintenance, availability of spare parts, qualified technicians, who are even hard to find in the developed world) and as a result is rarely operated up to design capacity;

• One viral particle can make a person sick. Normally, sewer water dumped at sea should not come in contact with a person for at least two days; this period of time allowing for viral die-off from ultraviolet radiation;

• Land-based discharge of sewage requires secondary treatment and viral aerosols are still an issue (e.g. spray irrigation of golf courses), which is maintained with difficulty in developing countries. On islands, land (e.g. overland flow,

Table 6. *Pesticide use in the Caribbean, 1988/1989.*

Island	Annual Use of Pesticides (Active and Inert Ingredients)	Number of USEPA Restricted Pesticides
Grenada	102,040 kg (224,488 lb.) (1988)	20
St Vincents	412,127 kg (906,679 lb.) (1988)	10
St. Lucia	354,083 kg (759,182 lb.) (Jan.-Oct. 1989)	13
Dominica	1,066,233 kg (2,345,712 lb.) (1988)	11

Source: Survey by DeGeorges [22], while USAID's Regional Environmental Management Specialist for the Caribbean, (REMS/C), in DeGeorges & Reilly [2] crops) is a major constraint as land availability can be an issue, while during the rainy season major holding ponds are needed;

• Solutions such as long outfalls with preliminary treatment, possibly land-based treatment and deep (not shallow) well injection, exist but are ignored by governments and developers, mostly out of ignorance, in favor of simple septic systems and secondary treatment package plants with short outfalls. A report in 2002 by Sealy of the Caribbean Water and Wastewater Association (CWWA) confirms this to still be the case. By 2017, it is hoped this is changing; [(23) ref in (14) ref].

• Once degraded, due to its slow growth rate, the coral reef system could take 100s if not 1,000s of years to come back, even if the source of pollution is removed and transplants of healthy coral are put into place. This is similar to the timeline for wildlife habitat to recover from the over-population of elephants in many land-based CBNRM programs in Southern Africa, once the elephant population is brought under control. If a mistake is made in over-harvesting wildlife, most wildlife populations, including elephant, can recover in ten years, while once the habitat is destroyed, it can take 100s of years for the vegetation and 1000s of years for the soil to recover;

• Most marine parks fail to deal with the major issues of land-based pollution and unless situated in a pristine watershed continue to degrade;

• Local artisanal fishermen are more often victims of degraded coral habitat by developers rather than the cause of the problem due to engaging in over-fishing and/or destructive fishing methods. While there is an increased need to work with artisanal fishermen to sustainably manage their fishery (e.g. breaking up the coastline/reef into fisher community-managed zones), they are not the major problem, which is coastal tourism as currently undertaken and land-based pollution in general;

• As in African parks and safari hunting areas with traditional hunters and pastoralists, hotel owners and dive operators often come into conflict with local fishermen, trying to stop access to areas that their families have fished for 100s of years in favor of exclusive high-paying clientele – SCUBA divers. This is analogous to wealthy tourists visiting Africa's parks and hunting blocks, while the local community is excluded from the lands of their ancestors - both fisher and rural communities compressed into areas that can no longer ecologically sustain them;

• Coastal tourism in the tropics negatively impacts local cultures, often turning the sons and daughters of fishermen into drug dealers, gigolos and prostitutes from the immoral Western values imported by tourists;

• Most governments and NGOs fail to recognize the problem of land-based pollution, assuming that marine biodiversity can be protected by declaring an area a park, by putting up marker and mooring buoys, banning fishing and educating sport divers not to touch the corals. The problem is orders of magnitude more complex than this, but this simplified approach brings in lots of money to the NGOs from donors and from publicity directed at an ignorant, uninformed public contributing to the wrong cause;

• Dams in Africa have also had major adverse impacts on marine & estuarine fisheries. Freshwater flows help support marine fish production, as many marine fish spawn in the brackish waters of estuaries or deltas, whose salinities range between seawater (35 ppt.) and freshwater. A decrease in freshwater flow and in nutrients due to dam construction affects nursery areas in a number of ways, including increasing salinity, allowing predatory marine fish to invade and reducing the available food supply. Linked to the aquatic food chain, mangrove ecosystems can also be adversely impacted. Thus dams and flow regulation emanating from these dams, if not properly managed, can impact estuarine/near-shore water quality (e.g., salinity, nutrient availability), adversely impacting aquatic life. As a result of dams on the Senegal River, it is estimated that fish production in the river and estuary has dropped by 90% and has probably also adversely impacted marine fisheries through the loss of nursery functions for mullets (Mugilidae), shrimp (Penaeidae), shad (*Ethmalosa fimbriata*) and other species having an obligatory estuarine life history stage. On the Gambia River, there is a strong risk that a coastal/estuarine fishery yielding about 23,000 metric tons/year valued at Dalasis 66 million (US$ 11 million)/year at mid-1980 conversion rates would be significantly degraded along with a major dieback of mangroves, critical to the detrital food chain, as a result of the proposed Balingho Anti-Salinity Barrage. Dams on the Zambezi River have had a major adverse impact on Mozambique's shrimp fishery. Prior to the Aswan High Dam (pre-1970), nutrients carried into the Mediterranean during the flood season resulted in large plankton blooms. This supported a large sardine fishery accounting for 30-40% of the annual Egyptian marine fishery yield. With the Aswan High Dam, and the elimination of the annual flood, the sardine fishery fell from 18,000 tons to less than 1,000 tons. The catch has since risen to a few thousand tons attributed to improved catch technologies, not necessarily a return in production. The shrimp yields at the mouth of the Nile also decreased by 67% with the elimination of nutrient supplies. Landings of other fish were 77% below pre-dam levels

• Other issues include damage to coral reefs by divers (education critical) and boat anchors (permanent moorings, or the dive boat floating with the divers' bubbles or a diver-towed buoy can solve this), dredging to create harbors, opening lagoons as harbors, filling in salt ponds/lagoons for housing developments, elimination of unsightly mangroves, unregulated harvest of coral and sea life for the aquarium trade, location of tourist lodges and lights too close to the beach affecting turtle nesting and sex ratios (the closer the eggs are laid to the waterline, the lower the temperatures and the more males are among hatchlings), as well as survival of the hatchlings (driven by lights from tourist hotels inland to their death); and

• Global issues such as planetary and ocean warming, the breakdown in the ozone layer, etc. have become increasingly important since the late 1990s in determining coral reef health, but often detract from people actually doing something about issues that they can physically address. A second concern associated with the burning of fossil fuels, in addition to global warming, is increased carbon dioxide (CO_2) levels and ocean acidification. Increasing atmospheric CO_2 drives more CO_2 into the ocean, lowering the pH (making the ocean more acidic) and lowers the concentration of carbonate which corals and other marine organisms use, in the form of calcium carbonate, to build their skeletons – these issues have to be dealt with at a global level by states such as through the Kyoto Protocol to the United Nations Framework Convention on Climate Change that addresses the burning of fossil fuels and resulting greenhouse gas (GHG) emissions. There are still major debates about long-term climate changes and to what degree they have been accelerated by humans as opposed to being part of a natural cycle. However, one thing is apparent: recent but temporary increases in ocean temperatures have resulted in major coral die-off and degradation.

• As noted, an important recommendation to ecologists and researchers is to take advantage of the incredible insight and knowledge of fishers and other traditional natural resource users of natural history and the environmental changes impacting these resources. The author has been humbled many times by the incredible knowledge of the fishers in Caribbean/Central America/Africa to the Mandinka hunters in the savannas of West Africa, to the Baka and Batwa Pygmies in the dense humid lowland forests of the Congo Basin, to the Bushmen of Namibia and Botswana. More than any other, in Belize local fishers explained how man, as described above, in Belize and surrounding countries adversely impacted the coral reefs and lobster fishery as a result of land-use changes and resulting land-based pollution. It is imperative that the knowledge of traditional hunters, herders, fishers, etc. be taken advantage of. The ecologist is trying to understand what has happened while looking at a window in time, while the traditional resource user is in the field every day seeing change take place, in addition to generations of knowledge and insight handed down to him/her by their ancestors. Some of the most insightful and intelligent individuals the author has ever met could not read or write. You must take advantage of this insight!

Ultimately, the tropical coastal zones' long-term economic potential is auctioned off for short-term gains, mostly out of ignorance. If a proper understanding existed by temperate climate developers and tropical governments, the cost of doing it right is likely the same as doing it wrong, especially if developers and governments pooled their resources. However, rectifying the problem once it is recognized can be more expensive. The following sums up fairly well what the principal author has observed over the last 40 years of diving.

"The coral reef crisis is almost certainly the result of complex and synergistic interactions among local-scale human-imposed stresses and global-scale climatic stresses. Both can produce direct and indirect chronic (long-term events such as land-based pollution and now ocean warming), and acute (short-term events that cause rapid damage on a reef such as storms and dredging, short-term but significant increases in water temperatures) stresses, leaving few, if any, parts of the ocean truly hospitable for healthy coral reef communities. Documented human stresses include increased nutrient and sediment loading, direct destruction, coastal habitat modification, contamination, and the very important chronic indirect effects of over-fishing. The major climate change factor that is becoming increasingly important for coral reefs is rising ocean temperatures, which have been implicated in chronic stress and disease epidemics, as well as in the occurrence of mass coral bleaching episodes. Also of concern are the effects of increasing atmospheric carbon dioxide (CO_2) on ocean chemistry, which can inhibit calcification — the deposition of the calcium carbonate minerals that are the structural building materials of coral reefs. Coral reef communities usually recover from acute physical damage or coral mortality if chronic environmental stresses (such as reduced water quality) are weak, and if the acute stresses are not strong or overly frequent. Coral reefs also withstand chronic stresses in the absence of acute stresses. The combination of acute and chronic stress, however, often results in the replacement of the coral reef community by seaweeds or some other non-reef system...Whereas remote oceanic reefs will be affected primarily by climate change, reefs close to human populations will continue to be affected by combinations of additional stresses (e.g. reduced water quality, physical damage, and over harvesting) that must be considered together to be understood and managed" [(24) ref in (2) ref].

A good example of the problems facing coral reefs is provided in the following set of photos taken over time by the US Geological Survey on one coral head from the Florida Keys (Figure 6).

Conclusion

Thus, while the concept of CBNRM, though originally designed for wildlife conservation in Southern Africa, has great merit for

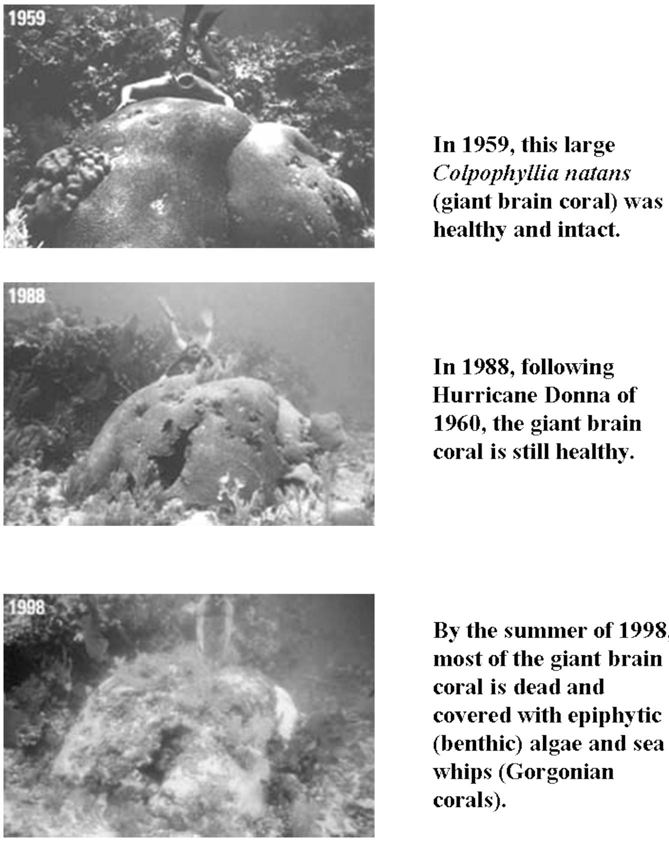

Figure 6. *The Florida Keys coral story: Then and now, 1959-1998. Source: U.S. Dept. of Interior (2002), U.S. Coral Reef Task Force (CRTF), U.S. Department of Interior, public domain in DeGeorges & Reilly [2].*

conservation in tropical marine environments, unless man-made sources of habitat destruction are addressed and fishermen are empowered to both benefit from, have input into management objectives and solutions, fisheries and their habitat in the near-shore tropical waters are in jeopardy, as are the lives of the many diverse groups making a living from these waters from fishers to tourism/ hotel operators to governments. The solutions are obvious, if the stakeholders are willing to address them.

Another key issue that must be addressed is how foreign aid is used to manipulate economies and politics by donors as a means of obtaining cheap natural resources with little or no beneficiation to the people living with these resources. A fine example is control/manipulation of local currencies, as France with the CFA that was originally pegged to the French franc at a rate of fifty CFA francs to one French franc (since 1994 devalued at 100/1) with each Francophone African country handing over at least 65% of its foreign reserves to the French Treasury. It is estimated that as much as $US 400 billion sits in a French account, many times the GDP of the CFA's largest economies [25]. Such manipulations help the West obtain cheap natural resources, while making products imported into the Developing World more expensive. The devaluation of the CFA at 100/1 has had a devastating impact on wildlife in many countries (e.g. Cameroon), people turning to poaching as other segments of the economy collapse [2].

Given today's level of poverty and human population growth, one of the actions that may be necessary in the 21st century is the reclassification of most neo-colonial protected areas to IUCN Category VI[1], since protected areas classified under other categories are being rapidly encroached upon and/ or poached out by alienated communities opting out for other land uses as a survival mechanism.

Creating classical protected areas of exclusion (e.g. IUCN Categories I-V), with the IUCN goal of 10% of a national territory under such regimes, can only happen at the expense of displacing and compressing rural people, including fisher communities around marine parks into areas where the resource to population is so low that the result is increased impoverishment and habitat degradation in the compressed areas. Once again, one can be sure that poaching and unmanaged mining of the resources by the impoverished communities will be the net result unless appropriate steps are taken as described in this review.

In Africa alone, it is estimated that there are as many as 14 million displaced persons from creation of parks and protected areas, 600,000 alone in Chad during the 1990s from the increase in national land under protection from 0.1% to 9.1%. Based upon a range of 1-16 persons/km^2, it is estimated using 1997 IUCN protected area categories I-V (1,540,430 km^2) that from 1.5 and 24.5 million (900,000 to 14.4 million using categories I-III) people have been displaced from creation of African parks and protected areas, mostly land-based. Using a density of about 25 persons/ km^2 and the same 1997 data, a range of from 22.9-39.5 million displaced persons is obtained, mostly within the last 3 decades of the 20th century [2]. Cutting people off from accessing the natural resources they depend upon and compressing them into areas that can't support them is not sustainable.

In Sub-Saharan Africa alone, human populations increased from about 96-114 million to 622 million people between the years 1900 and 2000 and within the next 50 years are expected to expand to between 1.5-1.8 billion people!

The handwriting is on the "coral" wall. The political leaders of both the Developed World and the tropical Developing World had better wakeup and address both terrestrial and marine resource issues described in this review, integrate traditional resource users into the management of these resources and protected areas through land use planning, and use donor funding for massive educational and nutritional (early childhood nutrition is critical to achieve maximum cognitive abilities) programs. The Developed and Developing World leaders must encourage/facilitate foreign direct investments (FDIs) that result in more transformation of natural resources in the countries of origin, with salaries based upon Purchasing Power Parity (PPP), not slave wages. These steps will help create a large middleclass as a means of taking pressure off mining the natural resource base for survival. Unless such steps are undertaken, the risk is that natural resources will become scarcer, poverty will increase and The Developed World, along with South Africa, will experience mass migrations from the Developing World that were never imagined; with both the Developed World and Developing World heading over the proverbial cliff!

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[1] **Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems.** Area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while providing at the same time a sustainable flow of natural products and services to meet community needs.

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