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"***Lophelia*** bioherms and lithoherms as fish habitats on the Blake Plateau: Biodiversity and Sustainability"

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ABSTRACT

With the decline of fisheries in shallow continental shelf, there is likelihood for commercial and sports-fishing pressure dipping down to deep-waters and deep-sea over the slope and seamounts. It is now well-known that dense aggregations of scleractinian coral *Lophelia pertusa* at bathyal depths (300 – 950 m) on both sides of the North Atlantic Ocean constitute fish habitats with high concentrations of non-target and commercial fish species. *Oculina* reefs off central Florida coast became the first MPAs in EEZ (Exclusive Economic Zone) in the US coast in 1980s but in 1990s inadequate action or failure in management strategies (mismanagement or lack of regulatory efforts to install VMS -Vessel Monitoring Systems in fishing vessels) resulted in habitat loss and fish decline (grouper and snapper species). The South Atlantic Fisheries Management Council (SAFMC) defined the *Oculina* reefs as Essential Fisheries Habitat (EFH) with a HAPC status (Habitat Areas of Particular Concern). North and east of the *Oculina* reserve are a series of *Lophelia* reefs that are primarily lithoherms (with some exceptions as the Agassiz Coral Hills off North Carolina, George, 2002). Along the Hatteras-Florida slope from Cape-Lookout to Cape Canaveral (300 to 500 m). *Lophelia* bioherms occur also at deeper depths down to 950 m at the eastern edge of the Blake Plateau. This paper describes six potential MPAs on Blake Plateau for the purpose of developing an ecosystem approach for sustainability and management of fisheries resources with emphasis on bicatch avoidance, species interaction, biodiversity characterization and an innovative new method to delineate the trophodynamics of the *Lophelia pertusa* ecosystem. This paper calls for prompt action to prevent further habitat damages.

INTRODUCTION

Since the discovery of the spectacular reefs in the deep-shelf off Norway, including the Sula Reef (Freiwald et al., 1999, Freiwald et al., 2002), considerable interest emerged on deep-water and deep-sea coral reef ecosystems at bathyal depths (150 – 800 m) in the oceans, particularly in the northeast Atlantic Ocean. Marine ecology of the deep-sea ecosystems is still in an early stage despite the fact that these reefs rival the complex tropical coral reef ecosystems in biodiversity, food chain complexity and fisheries potentials. Several questions are still unanswered and our knowledge is meager with reference to the reproductive biology of the reef-building scleractinian coral species Lop*helia pertusa*, its growth rate, life span, feeding ecology, benthopelagic coupling as for as food-uptake, co-evolution with other associated microbial as well as invertebrate species and prey-predator interactions in the community of coral colonies.

Since Rogers (1999) reported the occurrence of 868 invertebrate species associated with *Lophelia* reef habitats in the northeast Atlantic Ocean, further sampling has increased the total species number far above 100 species. Spatial (latitudinal) and temporal (seasonal, year to year and decadal) variations in the dynamics of the structure and function of the *Lophelia* reef ecosystem is poorly understood. To date no attempt has been made to develop a trophodynamic and precautionary model of the *Lophelia* reef ecosystem although George et al (2004) recently developed such a model for less complex *Oculina* reef ecosystem for the purpose of conservation and protection of these deep-water cold coral reefs.

George (2004a & b) pointed out the importance of *Lophelia* reef associated commercially fish species such as orange roughly *Hoplotethus atlanticus*, rock fish *Sebastes marinus*, ling cod *Molva molva*, tusk fish *Bromse bromse*. Bottom trawling and long-line fisheries caused considerable structural damages to these deep benthic habitats as reported recently at 64° N off Norway (Fossa et al., 2002). ROV surveys by Norwegian marine ecologists documented the presence of fishing gear on the reef areas and severe structural damages to the 3-dimentional frame-work of the coral colonies. The *Lophelia* reef complex off mid-Norway has traditionally been the target of heavy European fishing grounds as evident from internet ICES data files, reporting historical catch data from different sub-areas in the northeastern Atlantic Ocean. These cold coral beds were damaged by gilnet and long-line fishing as well, besides bottom trawling. Removal of predator species and significant bicatch or thrash fish death in trawling has made substantial alterations to over-all reef ecosystem structure and function as shown in the models for ecosystem-based fisheries management (EBFM) strategies (George et al, 2004). These precautionary models help policy-makers to make wise decisions to save these fragile ecosystems from further inevitable (if not regulated) destruction.

The crucial question now is the following. Is the threat to the cold coral reefs, by and large, the trawling gear damage only? In my opinion, as is the view of Rogers (2004) and Gianni (2004). fishing activities pose the “single big threat” to these ecosystems. Nevertheless, We can not ignore the following potential threats: (1) Oil-gas activities (2) Climate change (3) Influence of sediment cloud, from shrimp and fish trawling activities in adjacent soft-level-bottom sea-scape, with dumping of sediment clouds on *Lophelia* reefs (4) Acoustic pollution from NATO military installations that may interfere with marine mammals (baleen whales) with sonar perturbations near food-rich seamounts and deep-water coral ecosystems. The presence of monk seals in association with cold coral reefs off Hawaii islands illustrates the importance of these submerged home for these marine mammals and also for commercially important fish species.

With this background this paper, presented here at the science conference of the International Council of Ocean Explorations (ICES), focuses on the following three conceptual ideas (how, what and when) that address protection of cold coral reefs.

(1) **How** do we define hard-coral (scleractinians) dominated bioherms from soft coral (octocorals) dominated lithoherms eg. Blake Plateau cold coral reefs
(2) **What** latitudinal or longitudinal gradients govern fish distribution in cold coral reef ecosystems
(3) **When** can governments (national and international), NGOs and other stakeholders develop a joint action plan for biodiversity preservation and exploration ("Species Encyclopedia") and arrive at a sustainability agenda to conserve, protect and manage the cold coral reefs on the basis of the so called "Ecosystem-Based Fisheries Management" (EBFM)?

1. **Bioherms versus Lithoherms**: At the 2003 second international symposium on deep-sea corals in Erlangen, Lundalv et al. (2003) reported that there are two carbonate mounds at a depth of 80 meters in Kosterfjord on the west coast of Sweden, approximately 10 m in height, together 80 m in length and 40 m in width. This discovery was made possible by multibeam swath bathymetry and ROV video-survey from the R/V *Lophelia*, a research vessel operated by the Tjarnoe Marine Biological Laboratory in Sweden. This research vessel is specially outfitted for submarine observations and *in situ* experiments on *Lophelia pertusa* (Linneus 1758), a habitat-forming scleractinian coral species which has a growth rate of 5 to 25 mm per year (Freiwald et al, 2002). A complex thickets of a 3-dimentional frame work of colonies of the coral *Lophelia pertusa*) (Fig. 1) spreads over vast areas, offering an ideal hard bottom habitat for both fishes and invertebrates, as evident from several such cold coral reefs discovered from the fjords and deep shelf off Norway. These corals are either pink or white in color. In Koster Fjord on Swedish West Coast the live corals have white skeletons only and occupy today a small portion of the carbonate mounds at the southwestern flanks of both hills. *Lophelia pertusa* corals. The color patterns are seen in certain geographic regions, as in some Norwegian Fjords, but DNA sequencing data (Rogers, personal communication) indicate that the color variation is simply a genetic polymorphism within the same species.

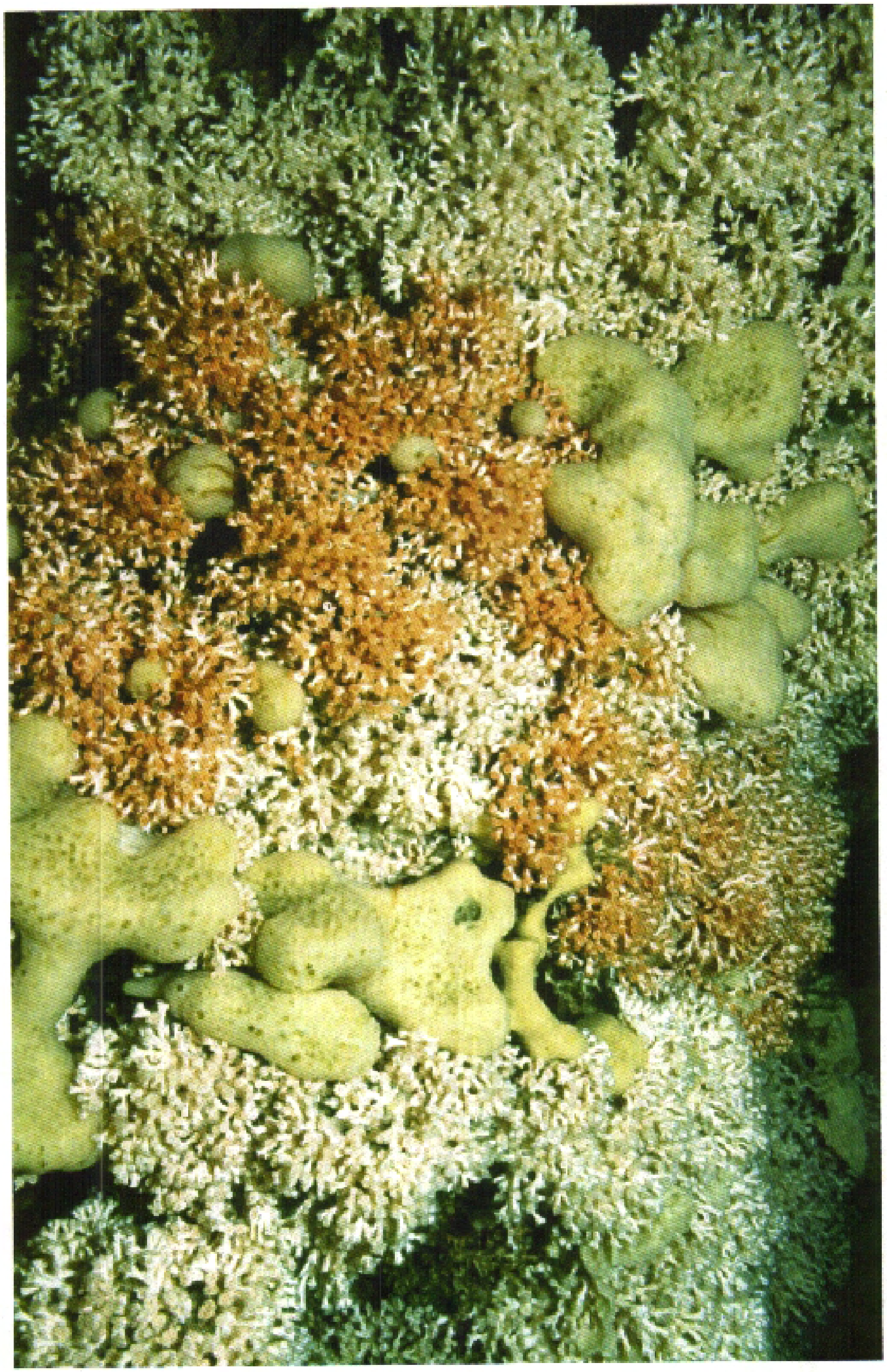


Fig. 1. *Lophelia pertusa* coral thickets in Trondenheim Fjord in Norway at 48 m. Photo courtesy of the Norwegian underwater photographer E. Svens..

Two vibercore samples were taken in November 2001, one from the northern slope and the other from the top of the southern hill, penetrating to 28 and 26 meters respectively. X-ray radiographs of these cores revealed that both cores contained dead and fossil *Lophelia* corals embedded in clay throughout the length of the core with occasional interruptions of bivalve layers replacing coral layers. Carbon-dating of the bivalve-dominated horizons (Lundalv et al, 2003), further confirmed by U/Th dating, established the age as 2000 – 3000 years. This finding clearly proves that these carbonate mounds are truly bioherms and not lithoherms as may be the situation in the seamounts with thick *Lophelia* patches (eg. Manning Seamount in the New England Seamount chain, personal communication, Dr. Timothy Shank of the Woods Hole Oceanographic Institution) and also submarine chaemosynthetic ecosystems on ridges, rock (and wrecks) with *Lophelia pertusa* in the Gulf of Mexico (Schroeder, 2002).

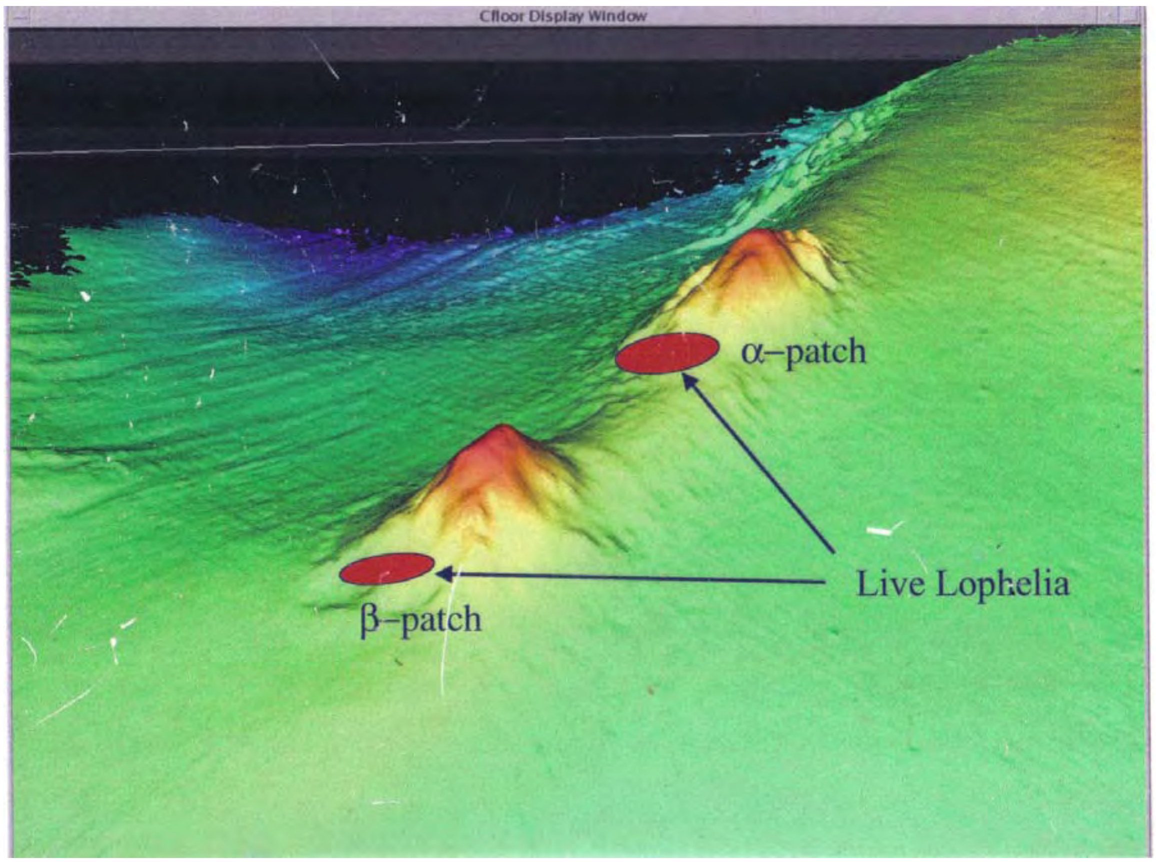


Fig. 2. Lophelia hills at 86 m in Koster Fjord, Sweden (Photo courtesy of Dr. Tomas Lundalv of the Tjarnoe Marine Biology Laboratory.

In 2003 at the International symposium on "Impacts of Trawling on Benthic Habitats", held in Tampa (Florida) under the auspices of US Department of Interior (US Geological Survey) and US National Marine Fisheries Service (MNFS, NOAA). I was invited to present the results of my research on the thermal tolerance of *Lophelia pertusa* in the Koster Fjord where George Institute for Biodiversity and Sustainability (GIBS) conducted research on *Lophelia* for 3 consecutive summers (2001 to 2003). In this paper I pointed out that surprisingly *Lophelia pertusa* functions metabolically within a certain wide thermal range (5 to 15 ° C) and feeds on small calanoid copepods (< 3 mm) with varying satiation levels and metabolism depending on thermal acclimation within this range of temperature tolerance (George et al., 2004). I postulated the following hypothesis. The disappearance of *Lophelia pertusa* at different time intervals from 3000 BC to present time was attributed to shift in thermal regimes and currents since the last Ice age. Consequent hydrographic changes in the Fjord in the early days prior to industrialization (18 th century) probably caused massive extinction. Nevertheless, the recent (last few decades) reduction of live coral coverage (restricted to a small area on the southwestern flank of these coral hills) is undoubtedly the result of unregulated fishing pressure on ling cod, tusk fish and red fish that are known to occur in association with *Lophelia* reefs. Obviously, these hypotheses call for further confirmation and therefore, we are planning research in the summers of 2005 and 2006 both in the Swedish West Coast and the Norwegian West Coast.

The first discovery of *Lophelia pertusa* reefs off North Carolina coast in the Hatteras-Florida slope (300 – 450 m) and over the Blake Plateau (400 – 750m) in the northwestern Atlantic Oceans was made during the R/V *Eastward* cruises by this author in collaborative research with late Dr. Robert J. Menzies and Dr. Gilbert Rowe of Texas A and M University (George, 1972; Menzies et al, 1973). George (2002). described these *Lophelia* reefs on the Blake Plateau as “Agassiz Coral Hills” with vertical reliefs of 3 to 80 m. In 1988 I conducted a cruise aboard R/V *Cape Hatteras* to study the *Lophelia* reefs on the so called “Charleston Bump” off South Carolina and this study revealed the presence of several fish species (including the wreck fish *Polyprion americanus*) associated with the Charleston Bump (a mini-seamount) which has a flat surface, high vertical profile and known to deflect the northward flowing ‘Gulf Stream’, thus creating current vortices.

Dr. George Sidburry of the South Carolina Marine Resources Center (personal communication), on the basis of his recent dives of the submersible *Johnson Sea-Link*, confirmed the presence of another fish species related to the orange roughy (*Hoplostethus darwini*). Recent dives of John Sea-Link in the *Lophelia* reefs off North Carolina, in a project supported by NOAA-Ocean Exploration, also revealed the presence of commercially important crab species. My colleague Dr. Stephen Ross (USGS) provided me with *in situ* photographs of the blackbelly rose fish (blue-mouth) *Helicolenus dactyloterus* from the *Lophelia reefs* off North Carolina. The red alfonsinos *Beryx* sp. (Fig. 3), now designated as the “logo” for the 2005 “3rd International Deep-Sea Coral Symposium” (IDSCS) in Miami (Nov. 28 – Dec. 2, 2005, is also found in the *Lophelia* reefs off North Carolina.

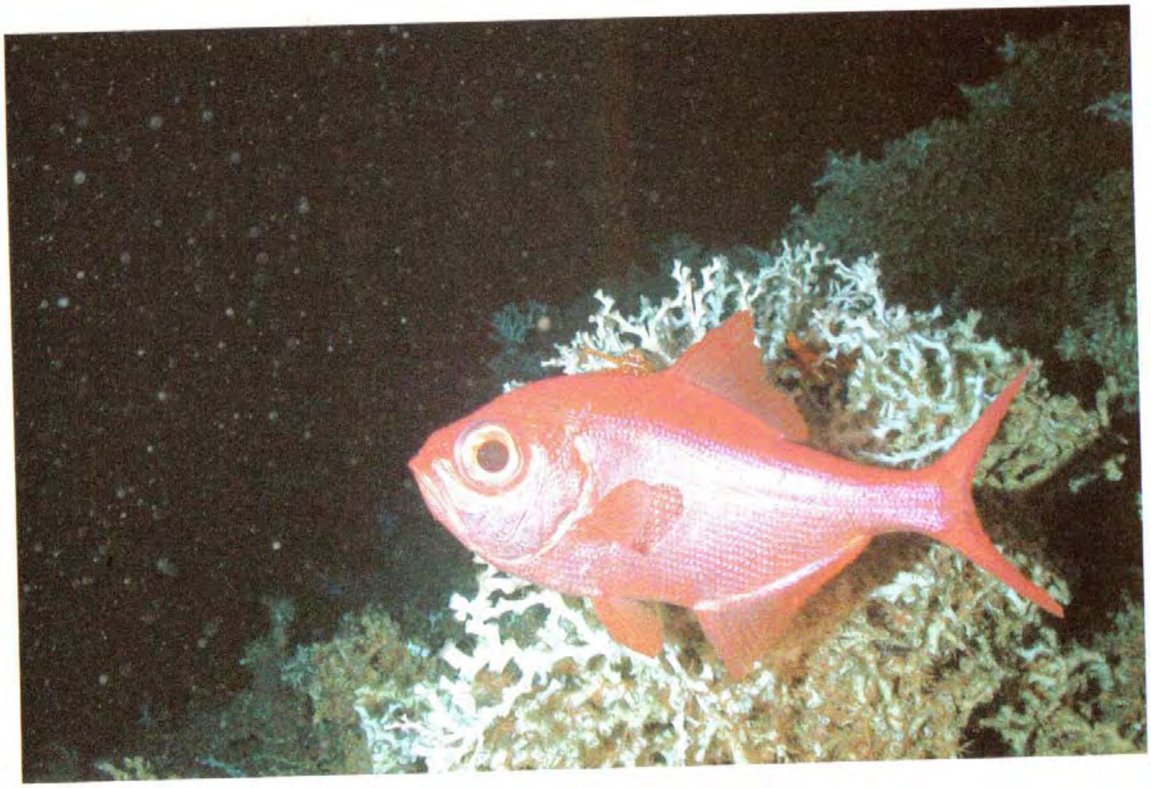
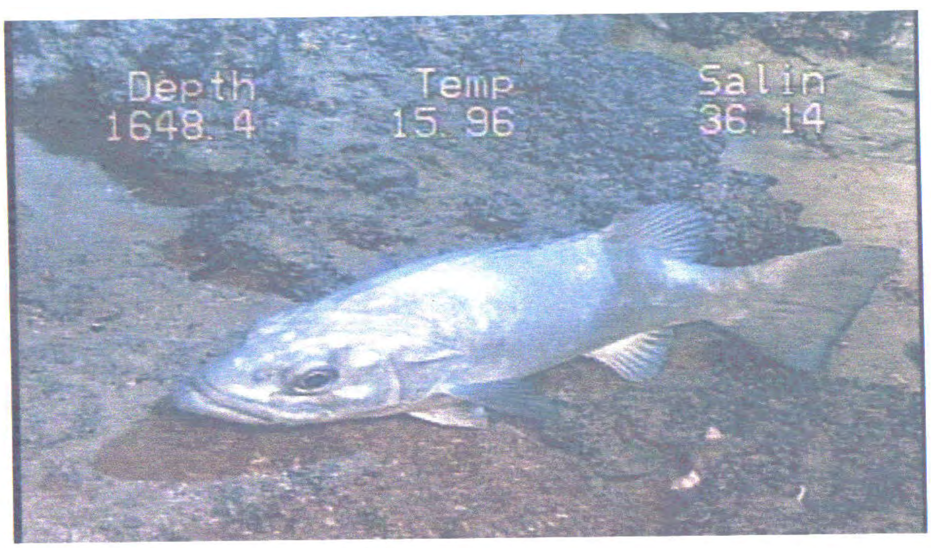


Fig. 3. Alfonsinos fish *Beryx* sp. from the *Lophelia* reef off North Carolina. Photo courtesy of Drs. Ken Sulak and Steve Ross (USGS).



Wreckfish weigh on average about 35 pounds and are associated with rocky bottoms.

Fig. 4. The wreckfish *Polyprion americanus* is a commercially important fish species associated with the *Lophelia* reefs in the Agassiz Coral Hills on Blake Plateau.

The wreckfish fishery started off South Carolina in 1986 with only two boats operating with a maximum of 12,000 pounds per trip. In two years the catch increased to 307,000 pounds by year 1988. In the following year in 1989 the wreckfish catch climbed to 3 million pounds with 40 boats operating. All the wreckfish fishing activity occurred within 75 square miles, not too far from the Charleston Bump at 300 m. On April 16, 1992, on the opening day of wreckfish season, South Atlantic Fisheries Management Council (SAFMC) recommended to limit individual transferable quotas (ITOs). The total allowable catch (TAC) was set at 2 million pounds for 1992-1993 to be shared by 49 applicants. Our knowledge about the biology and ecology of this commercially important bathyal fish species is still meager and this fish probably spawns in and around the *Lophelia* reefs off the Carolinas. With this in mind, I made four presentations before the regulatory and advisory committees of the SAFMC in 2003 and has recommended six *Lophelia* reef sites on the Blake Plateau (Fig. 5), each site given the EFH-HAPC status (Essential Fisheries Habitat –Habitat Areas of Particular Concern).

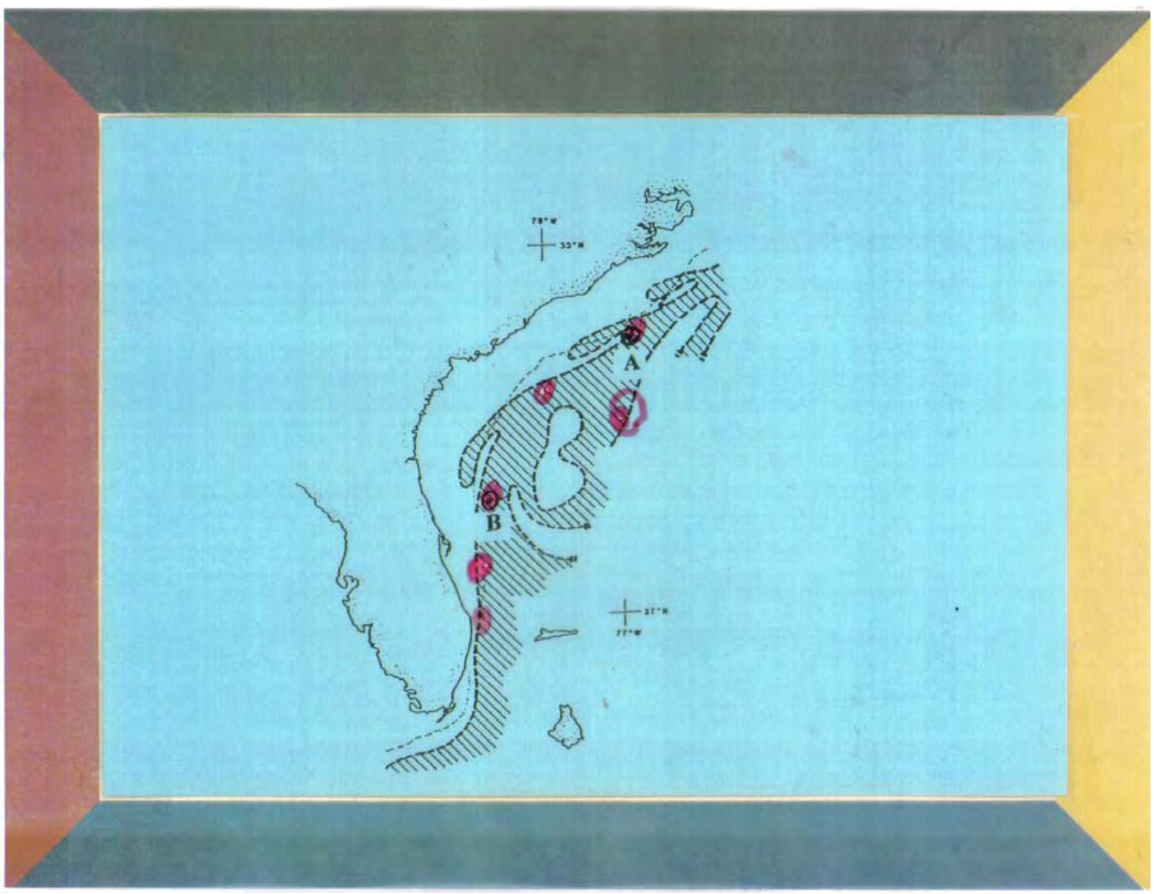


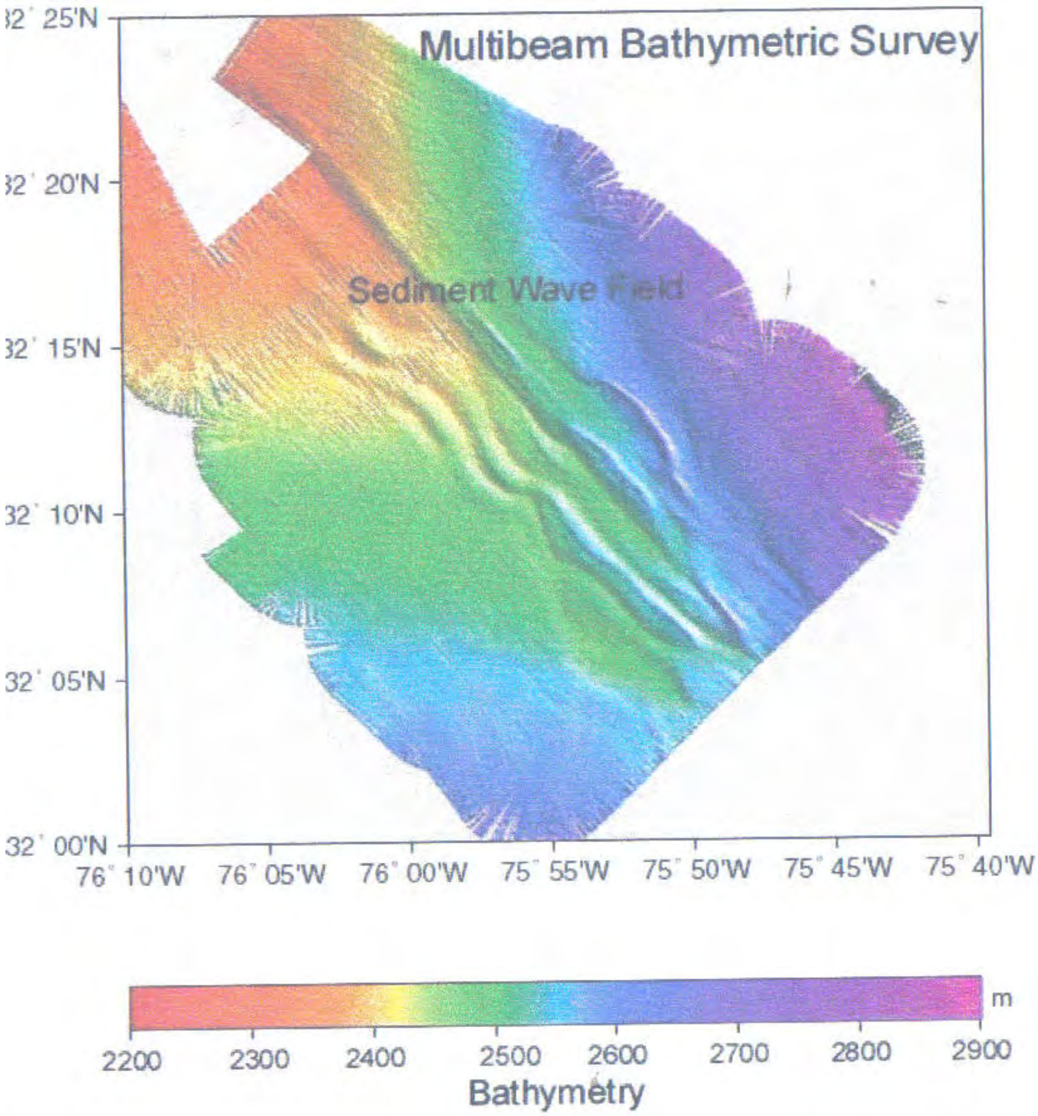
Fig. 5. GIBS - proposed EEZ MPAs as EFH-HAPC on the Blake Plateau off the southeastern United States in the “South Atlantic Region”, recommended to SAFMC by Prof. Robert Y. George (GIBS).

The exploration on the slope and deep-sea fish species off the Southeastern United States in the so called “South Atlantic Region” (not to be confused with the South

Atlantic Ocean), one of the 8 regions in the US EEZ zones under the jurisdiction of the 8 US fisheries councils that regulate fishing activities. began in the 70s and 80s with the plan to drill for oil and gas off the eastern seaboard of the United States. To day in the United States there are 30 million acres of nonproducing federal oil and gas leases. Oil companies and some rich individuals, who own these leases made little effort to drill and produce oil or natural gas. Environmental conservation intuitive convinced the US Congress to impose by law a moratorium to drill on the shelf, the Blake Plateau and the slope off US East Coast. Oil production from shallow depth to deep-sea is in full swing in the Gulf of Mexico, with concurrent environmental studies in progress under the direction of the US Mineral Management Service (MMS).

One good outcome of the early plans of oil drilling off US East coast is the 'Outer Continental Shelf (OCS) – Benchmark Program' that developed a 2 years intensive sampling by trawls and box corers in seven transacts from Cape Lookout (North Carolina) to Cape Canaveral, Florida from 40 m to 1000 m in four seasons for two consecutive years. The demersal fish and invertebrate fauna were thoroughly studied both in terms of biomass and biodiversity (George and Staiger, 1977). The results revealed the presence of cold coral reefs both in the continental shelf and Blake Plateau.

Our knowledge about the sea floor characteristics of the Blake Plateau is still meager. Since the early explorations of the coral banks occurring at the eastern edge of Blake Plateau at 800 – 950m (Steston et al., 1962), there have been hardly any geological and fine-scale bathymetric studies on Blake Plateau. The recent multibeam survey of the continental slope beyond the Blake Nose (Fig. 6) is an exception. . However, the first deep-sea coral symposium in Halifax, Canada aroused enormous interest on cold coral reefs among scientists (Watling and Risk, 2002, Willison et al, 2002)) but also awakened the policy-makers and managers to pay more attention to deep-sea coral ecosystems that are now susceptible to potential and irreversible impact by trawling activities on these vulnerable deep-sea coral ecosystems. With this realization, NOAA-NMFS and NOAA-OE, in cooperation with the Irish Marine Research Institute in Galway conducted a workshop (McDanaugh and Pugliese, 2003) and made recommendations for a trans-Atlantic expedition in 2005. One of the suggestions is to map the hard-bottom (coral zones) by multibeam bathymetry to get a good understanding of these submarine biogenic structures as was done off Norway (Fossa, 2003). On the Blake Plateau Paull et al. (2000) identified lithoherms with scleractinian corals with spectacular high-profile elevations of more than 40 m (always coral-capped). Reed (2002) also identifies both *Lophelia* and *Oculina* coral banks off Florida and off southeastern United States. Nevertheless what we do not know is whether all these numerous low and high-profile biogenic structures are lithoherms or bioherms. Therefore it is essential we do multibeam surveys and viber-coring to answer these important questions.



High-resolution bathymetric map of the Blake Ridge. The map shows a sediment wave field with long ridges running from the northwest to southeast. Such features may be important locations for gas escaping from the seafloor.

Fig. 6. The fine-scale bathymetry off Blake Nose over the slope from 2000 to 2800 m on the continental slope. *Lophelia* reefs are absent at depths beyond 950 m. *Lophelia* reefs are confined to what Menzies et al (1973) defined as the "Archibenthal Zone of Transitions' (AZT) where outer shelf fish species occupy the western part of Blake Plateau (300 – 650 m) and slope species occupy the eastern part (700 to 950 m).

2. Latitudinal Gradient in Fish Distribution associated with *Lophelia* reefs:

There is some evidence to prove that the commercially important deep-sea fish species, encountered in the *Lophelia* reefs off the Norwegian coast (ICES subarea IV) are not the same deep-sea fish community in the mid-latitudes over the Blake Plateau (with the exception of few species). For example, the following deep-water (bathyal) fish species are found in the Northeast Atlantic Ocean.

a. Alfonsinos – *Beryx decadactylus*
b. Golden-eye Perch – *Beryx splendens*
c. Ling – *Molva molva*
d. Blue ling – *Molva dypterygia*
e. Tusk fish – *Brosme brosme*
f. Argentine (greater silver melt) – *Argentina silus*
g. Roundnose granadier – *Coryphaenoides rupestris*
h. Roughnose granadier – *Trachyrhychus trachyrhynchus*
i. Blue-mouth – *Helecolenus dactylopterus*
j. Orange Roughy – *Holostethus alanticus*
k. Silver roughy – *Hoplostethus mediterraneus*
l. Wreckfish – *Polyprion americansus*

The following deep-water bathyal fish species are found in the Northwestern Atlantic Ocean:

a. Wreckfish – *Polyprion americanus*
b. Alfonsinos – *Beryx* sp.
c. Blue Hake *Antimora rostrata*
d. White Hake – *Urophyscis tenuis*
e. Gadid fish – *Urophyscis regius*
f. Offshore Hake – *Merruceus albidus*
g. 'Red Roughy – *Holostethus darwini*
h. Deep-Sea cut-throat eel – *Synophaubranchus kaupi*
i. Black-belly rose fish – *Heliolenus dactylotenus*
j. Tilefish – *Lopholatilus chaaemeleonticeps*
k. Black dogfish - *Centroscyllium fabriciei*
l. Granadier - *Coryphaenoides armatus*
m. Rat Tail fish – *Nezeumeia aqualis*

George (2002) reported greater abundance of deep-sea fishes, both commercially important and bicatch (non-targeted) fishes closer to the *Lophelia* reefs on Blake Plateau than at pteropod-ooze soft bottom sea-bed of the Blake Plateau at comparable depths (650 – 800 m). There are 24 deep-sea fish species, belonging to 20 genera and 16 families in and around the *Lophelia* reefs off North Carolina. On the contrary the fish biodiversity was low at the soft bottom study sites with only five common species, belonging to 4 genera and 3 families. George (2004) discussed the importance of developing MPAs (Marine Protected Areas) in the deep-sea, with agenda and an action plan that was develop during the 2003 - 10th Deep-Sea Biology Symposium, held in Oregon. A "Statement of Concern" was prepared, with signatures of 140 deep-sea biologists for designating MPAs and SPAs (Science Priority Areas) in the High Seas, This document was subsequently sent to Hon. Kofi Annan, General Secretary of the UN General Assembly (signed by Prof. Hjalmar Thiel, deep-sea conservation biologist in Germany, Prof. Robert Y. George, author of this paper and Prof. Andre Freiwald, convener of the "Second International Deep-Sea Coral Symposium" in Erlangen, Germany).

3. When do we develop a total ban (moratorium) on trawling over cold coral reefs in EEZ and High Sea?

The first American MPA in the EEZ , also defined as an Essential Fishery Habitat – Habitat Area of Particular Concern (EFH-HAPC), is the *Oculina* cold coral reef reserve off the Atlantic coast of Florida (Reed, 2002). This reef was fist described by late Dr. Robert Avent of MMS (Avent et al, 1977), The protected area is 90 square miles and due to illegal fishing of grouper and snappers the reef was obliterated, causing massive mortality of *Oculina varicosa* colonies. This coral species at shallow depth (20 – 40 m) is zooxanthellate and at deeper depths (60 to 100m) is azooxanthellate. The external appearance of *Oculina* reef resembles the deep-sea *Lophelia* reefs with mushroom-shaped thickets as in the Avent Reef off Florida (Fig. 7)

Much of the damage of the *Oculina* reef was also caused by excessive rock-shrimp fishing as illustrated in Fig. 8. The collapse of the Oculina reefs occurred in the early nineties, coinciding with the peak harvest of rock shrimps as seen in Fig. 8. It is therefore, important that it is crucial to regulate fisheries with strict law-enforcement. Immediate actions must be taken to introduce VMS (Vessel Monitoring Systems) in all fishing vessels. Above all, it is extremely important to define "Ecosystem-Based Fisheries Management" (EBFM), as implied in the new US Ocean Commission recommendations and as discussed recently in a policy statement in the policy forum of *Science* (Pikitich et al., 2004). An EBFM approach for seamounts and deep-sea coral reefs is now being developed and will be published as a Science article by this author with several American deep-sea coral biologists (George et al., 2004).

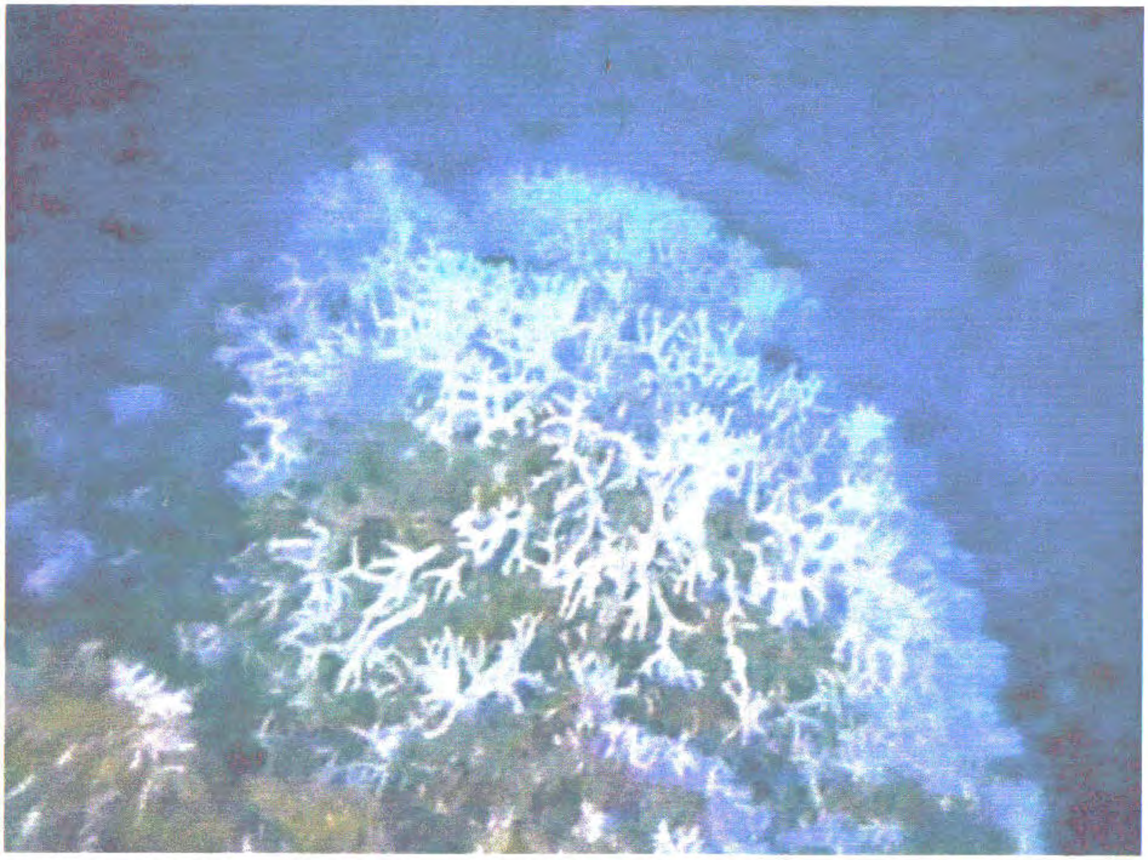
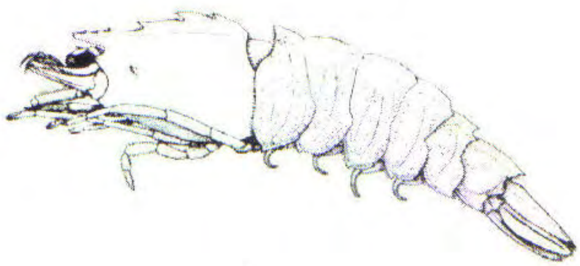


Fig. 7 *In situ* photograph of the Avent-*Oculina* reef reserve – EFH-HAPC site off Atlantic Coast of Florida

Rock shrimp, *Sicyonia brevirostris*



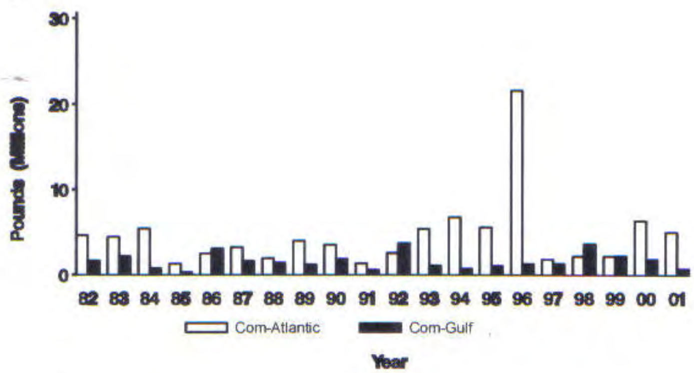


Figure 2. Total annual commercial landings of rock shrimp on the Atlantic and gulf coasts of Florida, 1982–2001

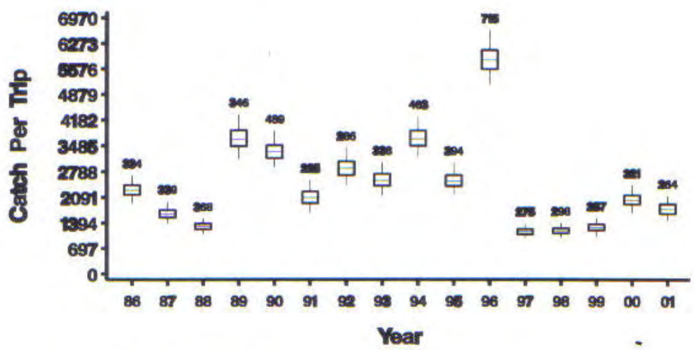


Figure 3. Annual standardized commercial catch rates (pounds) for rock shrimp on the Atlantic coast of Florida, 1986–2001

Fig.8. Rock shrimp Catch data off Florida Atlantic Coast.

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I wish to thank Dr. Robert Mahood, Dr. Gregg Waugh and Mr. Roger Pugliese of the South Atlantic Fisheries Management Council (SAFMC) for inviting me as an advisor to a series of workshops for conservation, protection and management of ecosystems of the southeastern United States. I am particularly grated to Dr. Douglas Rader, Senior Scientist of the US Environmental Defense (Raleigh, North Carolina) for supporting George Institute for Biodiversity and Sustainability (GIBS) in organizing a round-table discussion on "Integrated Ecosystem-Based Management" in April 2003 in Washington DC. I am thankful to US National Science Foundation, US Office of Naval Research, NOAA-NOS, Gulf Universities Research Consortium and Bureau of Land Management (BLM) of the Department of Interior for supporting my original research on deep-sea *Lophelia* reef communities on the Blake Plateau. I wish to thank the Mineral Management Services (MMS) and United States Geological Survey (USGS) for supporting GIBS as a co-organizer of 3rd International Deep-Sea Coral Symposium in Miami in 2005. The Swedish Royal Academy of Sciences supported my research at the Kristineberg Marine Research Station, Sweden. Dr. Tomas Lundalv, the Director of the Undersea Technology Division of the Tjarnoe Marine Biology Laboratory in Sweden enthusiastically helped my research on *Lophelia pertusa* both in the Koster Fjord and in the Norwegian Archipelago in the Skagerrak. This paper is dedicated to the memory and honor of late Dr. Robert Avent of MMS (the discoverer of the *Oculina* reefs) with whom I went on several cruises in the Gulf of Mexico and over the Blake Plateau.

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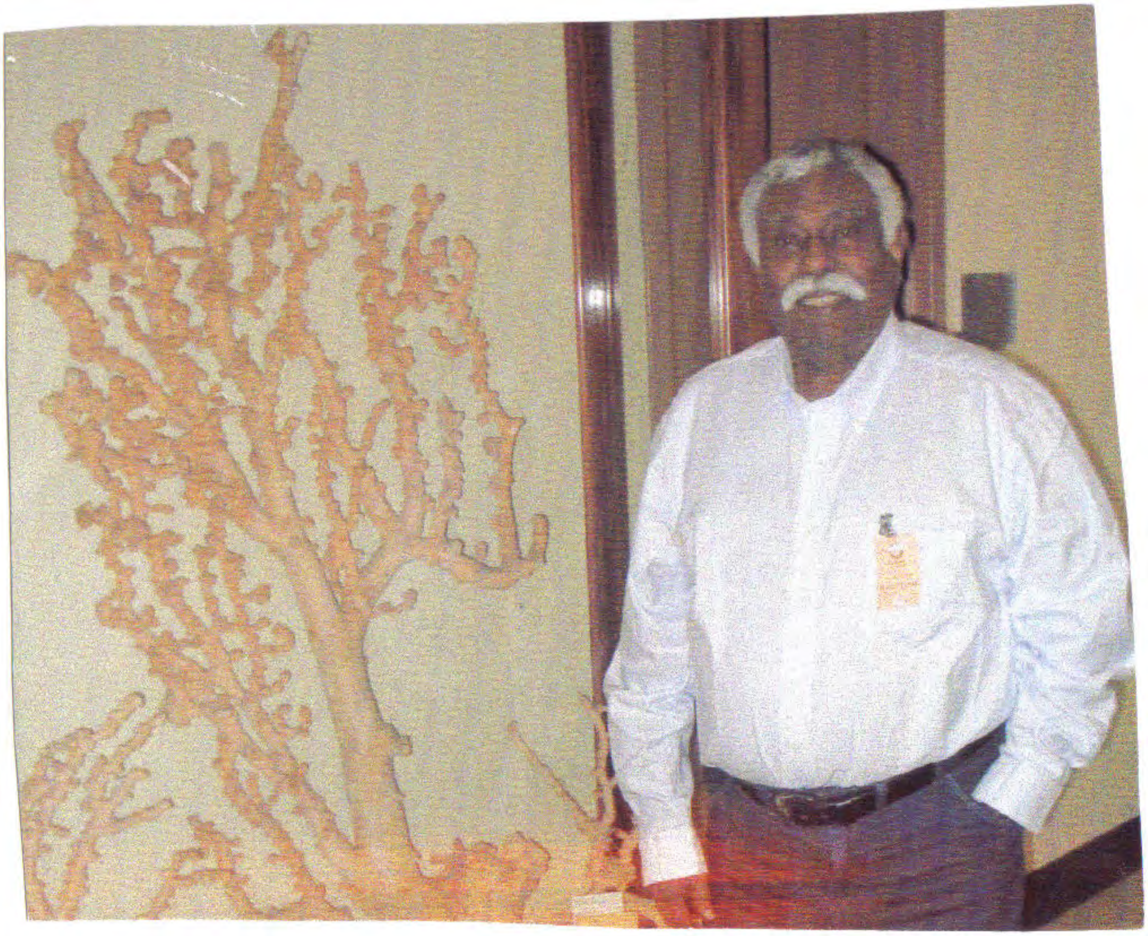
PHOTOGRAPH OF AUTHOR - DR. EOBERT Y. GEORGE (GIBS):

Photo taken with a tall tree-like *Paragorgia arborea* coral at the National Museum of Natural History at the Smithsonian Institution in Washington DC. This photo was taken by Dr. Stephen Cairns, Research scientist and Curator at the Smithsonian Institution.

“ **Imagine a rich gorgonean or scleractinian coral bed run over by the heavy doors of an otter trawl or a rock-hopper dredge or the giant trawl (like mercilessly clear-cutting a tropical rain forest with bull-dozzers) , that I saw during the ALBATROSS scallop survey cruise in the George Bank and Northeast Channel where *Paragorgia arborea* coral abounds!! Let us prudently use alternate methodology (AUV or ROV or manned submersible reconnaissance) for research and monitoring and ban trawling in all cold coral reefs with EEZ and the Seamounts in the High Sea, our global commons” --- Bob George (GIBS).**



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