Use of Remote Sensing and Geographic Information Systems To Support Spatial Management and Conservation of Marine Resources In Tropical Countries

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Abstract

Destructive fishing methods have degraded coral reefs and depleted fisheries in the Philippines and Indonesia. Both countries have passed laws to decentralize management of fisheries and the coastal zone. There is an urgent need to implement ecosystem management strategies. Conservationists and scientists have advocated spatial management involving the implementation of networks of marine protected areas (MPAs). A weakness of many MPAs created worldwide is that they often were created without sufficient scientific information. Many MPAs lack detailed benthic-habitat mapping. Some MPAs do not protect areas with important marine resources, because of a lack of knowledge about where these resources are located. Local people, who depend on the ecosystem services provided by coastal habitats, need to become involved with the development of spatial management strategies.

Landsat satellite imagery is often applied to delineate coral reefs, shorelines, and other coastal features using geographic information systems (GIS) in Indonesia and in other countries. Unfortunately, the spatial resolution of Landsat (30 square-meter pixels) is not sufficient to support population analyses of marine resources and zoning strategies that can benefit local communities. IKONOS imagery (4 square-meter pixels) will be utilized to map benthic habitats associated with coral reefs. Underwater surveys along transects can be used to enumerate species composition and densities. These data in combination with the IKONOS imagery can be utilized to estimate population numbers of fish and invertebrate species as a function of benthic habitat areas.

GIS is also being used to support participatory coastal resource appraisals (PCRAs) in which fishers are asked to provide information concerning where they fish and what species are caught at different seasons. Zoning strategies are being developed through a licensing system in which fishers are allocated space for fishing and other areas are set aside for mariculture. Co-management strategies can be applied to support spatial management of marine resources.

Introduction

Indonesia and the Philippines have many problems related to human population growth that have resulted in declining fish stocks and the loss of marine biodiversity caused by destructive fishing, overfishing, habitat degradation, siltation, and pollution [1, 2]. The destruction of marine habitats through cyanide fishing, blast fishing, and other destructive fishing methods such as kayakas and muro-ami have resulted in reductions in marine biodiversity and marked declines in sustainable yields associated with small-scale fisheries.

The tendency of government agencies has been to favor immediate needs for cheap protein and jobs, which tends to favor continued expansion of fisheries, export of high value commodities, and the use of destructive gears such as fine mesh gill and trawl nets, cyanide (for capture of live food and aquarium fish) and blast fishing. Fishing effort continues to increase in the artisanal and commercial sectors with almost no management. Christie [3] noted that imbalanced fisheries policies are slowly evolving toward strategies to implement ecosystem-based fisheries management (EBFM). There is a growing consensus of the need for sustainable fisheries management, but continued debate about how to achieve it.

Changes in Legal Structure

Three key Philippine laws (the 1991 Local Government Code, the 1997 Agriculture and Fisheries Modernization Act, and the 1998 Fisheries Code) presently shape fisheries policy and jurisdictions over the Bureau of Fisheries and Aquatic Resources (BFAR), the Department of Environment and Natural Resources (DENR), and Municipal Governments [3]. In addition, every five years the Fisheries Code mandates an updated national fisheries management plan, the most recent completed in 2005.

Since the passage of the Local Government Code (LGC) in 1991, the management of coastal areas in the Philippines has been assigned to the local government level [3]. Philippine coastal municipal governments have jurisdiction over marine waters and uses out to 15 km from shore. DENR retains control over permitting of structures proposed in marine and foreshore areas. BFAR, while technically mandated to manage all fisheries, has relinquished almost all management within municipal waters to Municipal Governments. Commercial fishing vessels, defined as greater than 3 gross tons, are supposed to fish outside municipal waters (except with Municipal Government approval to enter the 10-15 km zone) and are managed, albeit loosely by BFAR.

The LGC in the Philippines was a turning point in the legal-institutional landscape and supported the proliferation of community-based and municipal-level marine resource management projects [4,5]. However there is a growing realization that over-reliance on a limited suite of management tools, most commonly community-based MPAs, is problematic [3]. The spatial distributions of major fish stocks change by life stages and often straddle the15-km boundary, delineating the extent of municipal waters. Many commercial fisheries operations continue to fish within municipal waters throughout the country and enforcement capacity is not sufficient to restrain them.

Coastal management in Indonesia became decentralized with the passage of new laws (Laws 22 and 25 in 1999, and Laws 32 and 34 in 2004). The laws emphasize the decentralized process and enhance the community's role in managing resources [6,7,8]. These laws readjust the hierarchical relationship between the provincial and local governments. The local governments, both koto and kabupaten (cities and districts), have become autonomous and are no longer obliged to report to the provincial government hierarchy. The laws also give more authority to local governments to manage their resources in a sustainable way. This reflects a trend to give management autonomy to organizations and units providing direct services to local communities. More community and stakeholder involvement in the management of local public services is a concern in the decentralization context.

The endorsement of Law 22/1999 brought an opportunity to revitalize and institutionalize traditional rights and norms into local government systems. The empowerment of local authorities and the concepts of customary law and local territorial rights, which have a long history in Indonesia, allow for their adoption into local government policy.

Law 32/2004 established a decentralized coastal zone, under provincial administration that extends up to 12 nautical miles from the coastal shoreline. Included in this coastal zone, the local government (district) administration extends 4 nautical miles seaward from the shoreline. Under this law the central government of Indonesia has authority and jurisdiction to explore, process, and exploit the resources beyond the 12 nautical miles mark to 200 nautical miles, within the Exclusive Economic Zone.

Marine Protected Areas

The International Union for the Conservation of Nature and Natural Resources (IUCN) recognized that marine protected areas (MPAs) can serve a variety of objectives including: a) conservation through sustainable utilization of marine resources; b) protection of habitats at either local or regional (seascape) levels; and c) protection of biodiversity including plant and animal species [9]. The principal goal for all MPAs is conservation of resources to yield the greatest benefit for present and future generations. Salm [9]) recognized that area protection integrates many mechanisms and disciplines-international conventions, management authorities, species population protection, fisheries management, coastal zone management, and land use planning. They recognized the intrinsic linkage between marine, coastal, and terrestrial realms. Both land and water components need to be managed together.

Over the past decade, conservation organizations have become more actively involved in promoting the creation of Marine Protected Area Networks [10,11]. The IUCN-WCPA document acknowledged that MPAs cover a diverse set of tools and spatial, temporal, and resource management frameworks [11]. For the purposes of the document, the term MPA was used as the "single generic term to encompass the range of different protection and conservation strategies, from areas that allow multiple-use activities to areas that restrict all access."

Some organizations presently advocate the creation of community-based MPAs [5,12,13]. In the Philippines and Indonesia, the majority of MPAs that have been created are no-take zones [14]. White [15,16] noted that as the number of MPAs increased in the Philippines, there was a convergence of MPA programs with implementation of integrated coastal zone management (ICM). In alignment with Indonesian's decentralization policy, the Coral Reef Management and Rehabilitation Program Phase II (COREMAP2) is exploring implementation of coral reef MPAs [17]. The intention of COREMAP2 is to strengthen systems that already are supported by Indonesian laws, such as Law 31 of 2004 on fisheries, and Law 27 of 2007 on coastal zone management. District-managed MPAs or KKLDs are large areas, which will be managed by the districts for sustainable use, for example tourism, capture fisheries, or fish culture. Biodiversity conservation is an important secondary objective. Community-managed reserves or DLPs are much smaller than KKLDs. The DLPs will be managed by community groups supported by COREMAP2.

However, there is a growing realization that preserving marine biodiversity through the creation of no-take MPAs, in areas called hotspots, may not be working [18]. Focusing on protecting ecosystems vital to people's health and material needs makes more sense. Programs to conserve biodiversity can only work, if they include alternative livelihood programs to assist local people dependant on the ecosystem services provided by coastal habitats. Some of the ecosystem services include fisheries that provide food and income, and mangroves that provide building materials and fuel. Healthy marine resources contribute to the nature-based tourism industry, and export products such as marine and/or freshwater organisms for the aquarium trade, shrimp for human consumption, shells for the curio trade, hard corals for jewelry etc. Coral reefs and mangroves protect coastal communities from storms and tsunamis, reducing reconstruction costs etc.

One weakness associated with MPAs is that they are often created without sufficient information available concerning the locations of benthic habitats and their associated marine resources. To overcome this, we are presently implementing benthic mapping using remote sensing and geographic information systems as part of the CBUGs program.

CBuGS Program

The East Asian Seas and Terrestrial Initiatives (EASTI) and Telapak are non-government organizations (NGOs) dedicated to the conservation of biodiversity, protection of coastal and marine environments, and sustainable use of natural resources by local people. EASTI focuses on the creation of alternative livelihoods to foster sustainable use of natural resources for the benefit of local people. We recognize that workable strategies to implement ecosystem-based management must take into account the ecosystems that provide ecosystem services to local people.

The CBuGS strategy developed by EASTI and Telapak is an attempt to tackle the above problems by harnessing the individual strengths of the local communities (C), business systems (B), government agencies (G), and scientists (S) under one program; and focusing their collective talents on developing pragmatic solutions that can effectively address the region's critical needs for coastal habitat conservation, fishery management, and the generation of sustainable alternative livelihoods.

CBuGS Goals

(1) Conserve the region's rich marine and terrestrial biodiversity.
(2) Protect and restore habitats to improve resource productivity and food security.
(3) Increase the capacity of districts and associated communities to manage coastal resources.
(4) Alleviate poverty and reduce economic dependency.
(5) Develop mitigation measures from the impacts of climate change.

The main premise of CBuGS is that coastal-marine habitats and their associated fisheries need to be spatially managed. This necessitates the determination of fishing patterns, mapping seascapes, and spatially managing fisheries and aquaculture activities. The CBuGs strategy involves stakeholder participation to help conserve marine biodiversity, implement alternative livelihoods, and spatially manage coastal habitats and marine resources. Remote sensing (RS), benthic mapping and zoning using geographic information systems (GIS) are proposed to support spatial management, as cost-effective methods to manage marine and terrestrial ecosystems in the coastal zone. The approaches are derived from integrated community-based coastal resources management (CB-CRM) and the evolving science of ecosystem-based fisheries management (EBFM).

The CBuGS approach relies heavily on the use of spatial analyses to support the management of seascapes. It facilitates individuals from all walks of life to: (1) participate in the identification and assessment of community resources, (2) exchange information, (3) guide participants through policy development and the management-decision process, and (4) simplify program implementation and enforcement. CBuGS is based on the four major program components listed below (**Figure 1**).

The strategy being developed includes: a) workshops involving stakeholders to help identify problems and suggest possible solutions, b) participatory coastal resources assessment (PCRA) to assess ecosystem health and the status of natural resources, c) conducting interviews of fishers to assess socioeconomic conditions and use of GIS to spatially determine fishing patterns, d) implementation of alternative livelihood trainings, e) use of RS and GIS for mapping municipal boundaries and coastal habitats, f) restoration programs to reestablish coastal habitats, g) development of Coastal Resources Management Plans (CRMP) with stakeholder participation, and h) implementation of zoning using GIS, licensing, and other management measures as part of the CRMP developed for each municipality (Philippines) or regency (Indonesia).

Mapping Seascapes

Although habitat maps have obvious uses in coastal management, the term habitat is rarely defined explicitly [19]. Habitat mapping can be done using sonar, aerial photography or aerial hyperspectral sensors, and/or satellite imagery. Satellite imagery has the advantage of lower cost and the potential to map larger areas. A variety of satellites with differing spatial resolutions have been utilized to support benthic habitat mapping [20,21,22,23].

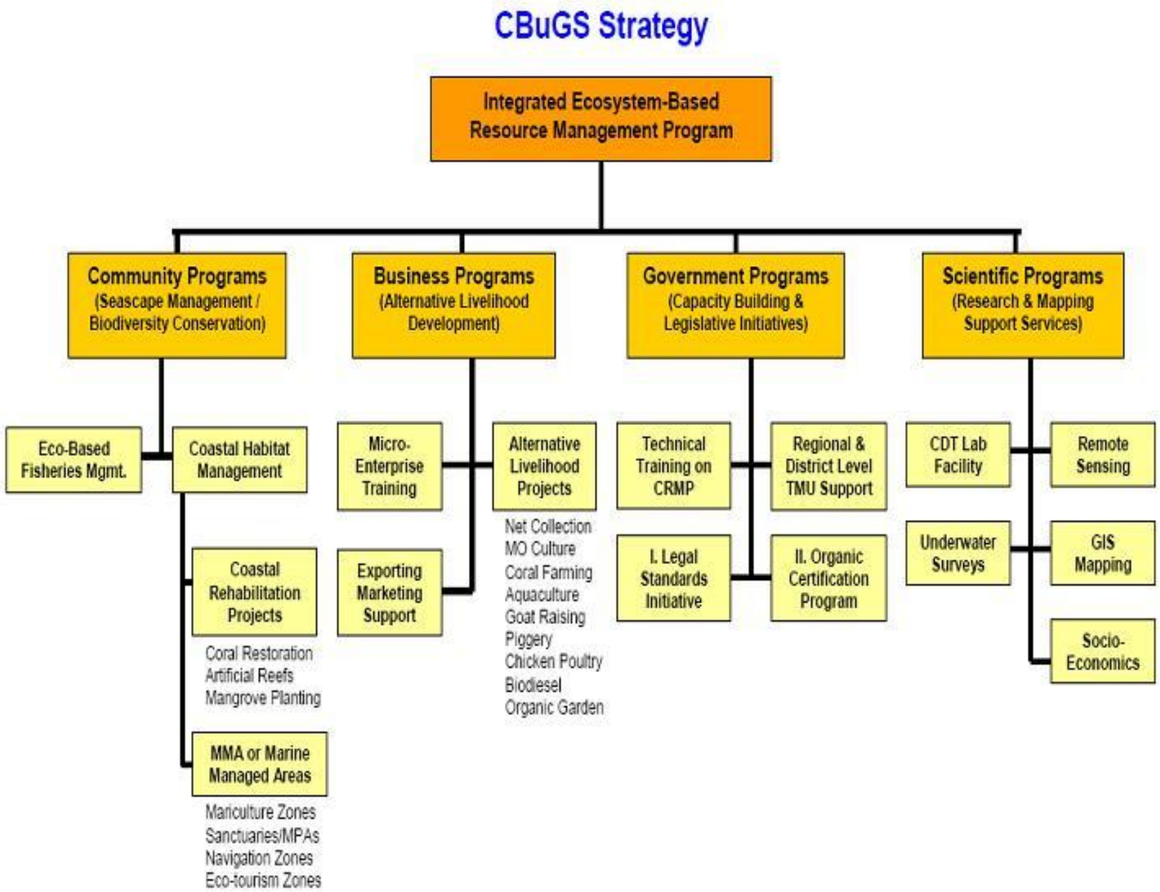

Figure 1. Elements of Community, Business, Government, and Science (CBuGS).

Owing to the difficulties and expense associated with conducting extensive surveys underwater, spatially distributed data of the appropriate type and detail are rarely available [22]. Remote sensing technologies have been used to map coral reefs since the early days of Landsat, and research into the use of RS technology continues with the advent of new sensors and data processing methods. Classification of broad substrate types is now routinely possible in clear shallow water, and water depth can be derived from a variety of data sources with varying accuracy.

Early studies that used Landsat TM and SPOT HRV sensors, only allowed discrimination of broad categories of benthic habitats such as coral, sand, seagrass, and algae [22]. Even with such broad classes, distinguishing between the coral and algae classes was difficult because the reflectance properties of both are dominated by chlorophyll-a. Another problem with the use of Landsat TM and SPOT HRV sensors has been their pixel sizes (30 m and 20 m respectively). They were not designed to register the small differences between substrate types, and classification accuracies are therefore rarely better than 60-70% for the four main classes of coral, sand, seagrass, and algae. Better spatial resolution of IKONOS (4 square meter pixels) and Quickbird (1.5 square meter pixels) satellite imagery has reduced but not eliminated this problem, and classification accuracies have increased to 75-85% using broad substrate classes.

IKONOS satellite imagery has been used to map marine benthic habitats at higher resolution [24]. The performance of Landsat-7 ETM+, ASTER, SPOT HRV, and IKONOS satellite sensors were compared [21]. The data sets provided different spatial and spectral resolutions. Five levels of benthic habitat complexity were defined (with three, four, five, seven, and nine classes). Overall accuracies of Landsat-7 ETM+ compared well with IKONOS for low to moderate habitat complexity mapping. For high-complexity mapping (nine classes), IKONOS performed the best.

Andréfouët [25] analyzed ten IKONOS images of different coral reef sites around the world. IKONOS classification results were compared with classified Landsat 7 imagery for simple to moderate complexity of reef habitats (5-11 classes). Overall accuracies for both sensors show a general linear trend of decreasing accuracy with increasing habitat complexity. The IKONOS sensor performed better with a 15-20% improvement in accuracy compared to Landsat. For IKONOS, overall accuracy was 77% for 4-5 classes, 71% for 7-8 classes, and 65% for 9-11 classes.

IKONOS imagery can allow the spatial delineation using GIS of benthic habitats such as patch reef, fore reef, spur and groove reef, back reef areas, seagrass meadows, salt marsh, municipal areas, forests etc. [23]. Of particular interest is that underwater fish counts were related to the benthic habitat classes. Replicate fish counts were made at seven measurement stations across the study area in the Diego Garcia (Chagos Archipelago). The study suggests that satellite remote sensing is capable of predicting habitat complexity at a scale that is relevant to fish.

The National Ocean Service within NOAA has used IKONOS imagery for coral reef mapping in Hawaii and associated states in the western Pacific, and plans to use it for mapping coral reefs nationwide. Ground-truth surveys are being conducted to validate the classification of benthic habitat classes [26]. EASTI plans to use similar methods associated with IKONOS imagery and divers for ground-truthing to delineate benthic habitats associated with coral reefs in Indonesia and the Philippines.

Underwater Surveys

Divers using video cameras can record swaths along underwater transects. The video imagery will be analyzed to determine the predominant genera (and where possible species) of corals as well as record the health of benthic habitats. Fish species also will be enumerated along transects. The numbers of fish per square meter associated with various benthic habitats will be recorded along transects. The species numbers per square meter will be expanded to estimate population numbers by species associated with the total area for each class of benthic habitat. While the benthic habitat mapping using IKONOS, only needs to be done once; inter-annual trends in abundance of fish species will be determined from annual underwater surveys. This constitutes a scientifically sound methodology for the assessment of fish species population trends; which can be used to support management of the food fish and aquarium fish fisheries.

Habitat Restoration

Coral reefs, mangroves, and seagrass beds provide cover to protect species from predation. These habitats also support benthic invertebrates that provide food to support the growth and production of fish. Habitat restoration programs will be implemented (e.g., planting mangroves, restoration of coral reefs through placement of coral fragments, creation of artificial reefs) to support fish and invertebrate species.

Development of Coastal Resources Management Plan

The CBuGS program fits into the decentralization strategies being implemented by the Indonesian and Philippine governments. The regencies (districts) in Indonesia in conjunction with their associated municipalities have the authority to set regulations to manage the use of coastal habitats and to manage fisheries. A holistic approach is needed to support local management. Municipalities need to work together to establish a common set of regulations, to create a licensing system, and to allocate zones licensed by the users through creation of a CRMP.

Implementation of TURFs

MPAs are a common mechanism for trying to accomplish conservation objectives, while still allowing for economic development [27]. Reconciling different uses is, however challenging. Multiple-use zoning has emerged as one way of achieving several objectives helping to ease current and potential conflicts among user groups. Zoning plans can be used to delineate zones where particular human activities are allowed and others are not. Developing successful zoning schemes requires information on the biophysical characteristics of the area, the activities of and conflicts among user groups, and conflicts among users and their environments.

With EASTI's programs, initial regulations and licensing will be based on the information gathered from the socioeconomic surveys, from benthic habitat mapping, and from underwater surveys. The allocation of space for aquaculture and mariculture and/or for fisheries can be done through a licensing system. Allocating territorial use rights for fisheries (TURFs) creates stakeholders with a vested interest in protecting their areas [28,29]. Likewise, TURFs can be allocated for mariculture. The stakeholders have the right to exclude others from their TURFs. Hence, the implementation of TURFs provides a self-enforcing mechanism for protection of marine resources.

The implementation of TURFs in association with community-based training programs fits into a strategy involving multiple zones, including TURFs and no-take MPAs. Local people are more likely to accept the creation of no-take MPAs; if other zones also are created that support livelihoods, such as mariculture of finfish, shellfish, and organisms for the aquarium trade. Use zones can also be used to support management of sustainable fisheries.

Micro-Enterprise Trainings

The strategy depends heavily on providing alternative livelihoods that can quickly create income for the communities. Once the communities see economic benefits, they become willing to support PCRA, RS and GIS-based mapping, underwater surveys, planning, zoning, and other resource management strategies that ensure benefits for the community through sustainable use of coastal resources.

The point of entry includes trainings for the harvest of marine ornamental (MO) aquarium fish with barrier nets, and rearing post-larval MO fish for export to the marine aquarium trade. Telapak and EASTI have worked with community-based cooperative enterprises in Bali to export net-caught MO fish (Les), to deploy and harvest artificial base rock, and to rear stony corals and soft corals from fragments on coral farms (villages of Serangan and Les). Markets for MO fish and marine invertebrates have been established in the United States, Canada, and Europe. Telapak and EASTI have already demonstrated the economic viability of these training programs in Indonesia.

The income generating potential must be high enough to bring households above the poverty level. A combination of enterprises will be implemented to raise or augment incomes for local people. The economic gains motivate the communities to participate in resource protection and conservation activities.

It is expected that many of the businesses will be site specific. Some of the micro-enterprises that are planned as pilot projects include the culture of freshwater aquarium fish, such as species endemic to Sumatra, Sulawesi, Kalimantan, and Irian Jaya; mariculture of MO fish reared from post-larvae, culture of mud crabs, abalone, shrimps, seaweeds, oysters, mussels, giant clams, and rabbit fish (siganids); rearing ducks and poultry; growing jatropha grass to extract biodiesel; and other forestry related projects to address the upstream problems affecting the coastal and marine environment.

EASTI is presently collaborating with BFAR and communities in the Philippines to promote the culture and export of freshwater aquarium fish and conducting net-trainings to support sustainable harvest of MO aquarium fish. It is also collaborating with Xavier University and communities to conduct similar programs in Mindanao. The CBuGS programs are being implemented through collaboration with communities, government agencies and other partners. Zoning also will play a role in the location of mariculture parks and freshwater aquaculture sites in the coastal zone.

Summary

CBuGS is a holistic ecosystem-based management strategy that benefits local communities. It builds on previous programs; but puts more emphasis on the use of RS and GIS to support spatial management of coastal habitats and marine resources. It relies on the participation of local people to support the protection and sustainable use of areas, through the development of sustainable enterprises tied to zoning.

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