

The Sulu-Sulawesi Sea: Environmental and Socioeconomic Status, Future Prognosis and Ameliorative Policy Options

The Sulu-Sulawesi Sea, with neighboring Indonesian Seas and South China Sea, lies at the center of the world's tropical marine biodiversity. Encircled by 3 populous, developing nations, the Philippines, Indonesia and Malaysia, the Sea and its adjacent coastal and terrestrial ecosystems, supports ca. 33 million people, most with subsistence livelihoods heavily reliant on its renewable natural resources. These resources are being impacted severely by rapid population growth ($> 2\% \text{ yr}^{-1}$, with expected doubling by 2035) and widespread poverty, coupled with increasing international market demand and rapid technological changes, compounded by inefficiencies in governance and a lack of awareness and/or acceptance of some laws among local populations, particularly in parts of the Philippines and Indonesia. These key root causes all contribute to illegal practices and corruption, and are resulting in severe resource depletion and degradation of water catchments, river, lacustrine, estuarine, coastal, and marine ecosystems. The Sulu-Sulawesi Sea forms a major geopolitical focus, with porous borders, transmigration, separatist movements, piracy, and illegal fishing all contributing to environmental degradation, human suffering and political instability, and inhibiting strong trilateral support for interventions. This review analyzes these multifarious environmental and socioeconomic impacts and their root causes, provides a future prognosis of status by 2020, and recommends policy options aimed at amelioration through sustainable management and development.

INTRODUCTION

This review provides a short précis of the results and recommendations arising from the Global International Waters Assessment (GIWA) for the Sulu-Celebes (Sulawesi) Sea (1), undertaken by more than 30 regional experts.

Physical Characteristics and Climate

The Sulu-Sulawesi Sea is oceanographically, geologically and topographically diverse (2, 3). The island of Borneo, the northeastern portion of which (Indonesian East Kalimantan and Malaysian Sabah) forms the southwestern border, lies on the Asian continental shelf and is geologically stable. Most of the remaining islands of northern Indonesia and the Philippines are subject to more tectonic activity and volcanic instability, with both active and dormant volcanoes, several exceeding 3000 m in height.

The Sulu-Sulawesi Sea is oceanographically well defined, by the Palawan trough to the north and by a promontory from Sulawesi Island to the south, and the Bohol Sea between the Visayas and northern Mindanao. The Sea is recognized as a Large Marine Ecosystem (LME) (4) with an area of about 900 000 km², comprised of the 2 large seas (Sulu and

Sulawesi) separated by the Sulu Archipelago; and several smaller seas—the Sibuyan, Visayan and Camotes Seas in the northeast and the Bohol Sea further south between Bohol and Mindanao. These 'marginal seas' are mostly enclosed by island land-masses.



Figure 1. Location and GIWA assessment boundaries of Sulu-Sulawesi (Celebes) Sea and adjacent GIWA subregions.

The Sea lies within the subequatorial and equatorial zones (from latitudes 1° – 14° N), with a tropical monsoonal climate producing annual rainfall in excess of 1000 mm in most areas (ranging from $< 500 \text{ mm} - > 5000 \text{ mm yr}^{-1}$) and annual minimum temperatures of $> 20^\circ\text{C}$ other than in the highlands. The northern and central parts are affected by revolving tropical storms (typhoons) passing from the Pacific into the South China Sea through the Philippines Archipelago during the southwest monsoon months, bringing intense rains and destructive winds. There are more than 300 watersheds, with the major river systems being the Sandakan and other river catchments of Sabah; the Kayan, Ketai, Berau, Sesayan, and Sembakung Rivers of East Kalimantan; and the Mindanao River and tributaries, the Agusan River and tributaries (emptying into the Bohol Sea), the Libuganon and Sindangang Rivers of Mindanao. There are numerous smaller rivers and streams flowing from the mountainous interiors of most of the islands (2, 3).

Many of the coastlines were originally fringed by mangrove forests, seagrass beds, and coral reefs. Fringing reefs are very well developed, away from the major river estuaries. Offshore, series of large platform reefs and atolls are developed—as exemplified by the Tubbataha reefs of the Sulu Sea. All major reef types, fringing, patch-platforms (including 'barrier') and atolls, occur, with a total estimated reef area of more than 20 000 km² (5, 6). Most of the coastal waters, particularly around the Visayas Islands, are shallow (< 200 m deep) and influenced by both marine and river/terrestrial inputs. By contrast, the central Sulu Sea has depths exceeding 4000 m and the Sulawesi Sea has depths greater than 5000 m (3, 5, 6).

The Sea receives an influx of surface oceanic water from the North Equatorial Current, flowing into the area from the NE through corridors in the Visayas and northern Mindanao, with subsurface flow in the opposite direction. The Sulu Sea's surface currents flow from the south in summer, whereas the winter currents follow a counterclockwise gyre. The Sulawesi Sea's strong currents, deep trenches, seamounts and active volcanic islands result in a complex oceanography (4, 6). Surface waters flow south through the Makassar Strait and also between Sulawesi and Morotai-Halmahera, contributing to the Indonesian throughflow from the Pacific to the Indian Ocean. Local current patterns form complex eddies and counter-currents, particularly in the vicinity of the Visayas Islands and coast of N Sulawesi.

The Sea, with its terrestrial, coastal and marine ecosystems, lies within the global center of tropical biodiversity (7), being located near the junction of 3 major biogeographic zones (8). With the neighboring Indonesian Seas, the Sulu-Sulawesi Sea supports megadiversity (9), exemplified by more than 500 species of reef-building corals and 2500 species of marine fishes (7, 10). Five species of sea turtles (Green, Hawksbill, Olive Ridley, Loggerhead and Leatherback) and at least 22 species of marine mammals occur (4), including Sperm Whales and Dugongs, the latter present in Palawan and Sarangani provinces (Philippines), although these were once more common and widespread.

Protected Areas

In total, there are more than 100 terrestrial and 200 marine protected areas (MPAs), many of which contain coral reefs (6, 10). Several MPAs are of particular importance and relevance to the present analysis:

- Tubbataha Reef Marine Park: A World Heritage site in the Sulu Sea, comprising some 33 200 ha and situated inside the Palawan Man and Biosphere Reserve (1 150 000 ha). The Tubbataha MP, a unique example of an atoll with high diversity and density of tropical marine biota, is among the most biologically diverse coral reef systems in the Philippines, and is of great importance for maintenance and replenishment of harvested species in the greater Sulu Sea.
- Turtle Islands: In the Sulu Sea offshore from N Sabah, established for conservation of marine turtles in a bi-national agreement between the Philippines and Malaysia (1, 11).
- Bunaken National Park: In the Sulawesi Sea, near Manado in N Sulawesi, Indonesia, comprising some 90 000 ha of reefs, mangroves, and seagrass beds and a recently discovered population of a second species of the 'living fossil' fish *Coelacanth* (*Latimeria manadoensis*) (12).

At the largest spatial scale, the entire coastal and sea area between Malaysian Sabah, Indonesian East Kalimantan and the Philippines is recognized as a special management area (Sulu-Sulawesi Marine Eco-region - SSME) by WWF (11), ranked as one of their top 4 global priority sites (#1 in Asia-Pacific, R. Trono, E. Micalat, WWF Philippines pers. comm.) for coastal and marine management.

Population and Culture

The human population is comprised predominantly of peoples of Indo-Malay origin. Peoples of other ethnic origins are also present, some forming ancestral tribal groups, particularly in Borneo, others of more recent arrival, e.g. Chinese and Indian traders. Within these broad ethnic groups, there are substantial cultural differences and various forms of religious belief, principally Christianity and Islam. There is a broad acceptance of different religious viewpoints (1), although racial, cultural, and religious tensions have been building in some areas in recent times, concomitant with the economic difficulties of the 1990s. Southern Mindanao and islands of the Sulu Archipelago have an Islamic separatist movement—the MNLF/MILF—that has been involved in civil and political instability in the area (1).

Disaggregation of national statistics suggests that the total population surrounding the Sea and its catchments is ca. 33 million, of which about 75% are in the Philippines (25 million), 21% in Indonesia (7 million in East Kalimantan and N Sulawesi) and 4% are in Malaysian Sabah (< 2 million) (11, 13). The population is distributed in the larger urban settlements (with half the Philippines population residing in urban areas), and throughout hundreds of villages spread along the coast, across the lowlands and into the highlands. The larger urban centers include Davao City (> 2 million and the administrative and commercial hub of Mindanao), Zamboanga City (> 2 million, W Mindanao), Manado (N Sulawesi), Sandakan (Sabah), Puerto Princesa (< 1 million, Palawan), Cebu City (Cebu), Bacolod City (Negros), Iloilo City (Panay), Tacloban City (Leyte) and Naga City (southeast Luzon) (1).

Populations are increasing at between 2 – 3% annually (2.4% for Philippines) and Sabah is also experiencing substantial immigration, of the order of 4% annually (11, 13). A 5% annual growth rate is occurring in the Malaysian area, due to immigration from Indonesia and the Philippines, in part through a previous bilateral transmigration project developed to ease population pressures in Indonesian Java (11). There is also substantial emigration to overseas countries, but much of this is for extended work periods (1 – 5 years), rather than as permanent migration. Population densities are generally > 100 persons km⁻², but range to > 200 persons km⁻² on the Philippine islands of Negros, the Visayas and Mindanao (11, 13). Many people live in poverty, with the poverty rate for the Philippines estimated at 36.8%, and with illiteracy at 5% in 2001 (14). Illiteracy rates are higher in Indonesia and Malaysia (both at 12% in 2001).

Socioeconomics

Almost the full gamut of economic activities, from subsistence agriculture and artisanal fisheries to high technology industries, occur. Rapid economic expansion during the 1980s has slowed recently, and GDP and economic growth for the 3 nations declined and stabilized over the past several

years (14). The agriculture sector contributes between 15 – 30% of GDP, and is comprised of large-scale plantations and smallholders who constitute the majority of the farming population. Fertile lowlands and hill areas have been extensively developed for rice production, as paddy fields and upland terraces, palm oil, and coconut plantations. Lowland areas and river floodplains also support mixed agriculture. Forestry remains a major industry in parts of E Kalimantan and Sabah, and less so in the Philippines, where much of the harvestable forests have already been exploited or are now protected.

The Philippines, Indonesia, and Malaysia obtain 60 – 70% of their animal protein from marine fishes (11, 13, 15). The marine fishery contributes significantly to the economies of Indonesia and the Philippines, and to a lesser extent in Malaysia. For Indonesia, government statistics indicate that N Sulawesi and E Kalimantan provide some 11% of the total national marine fishery landings (1997) (15). The fishery, although multispecies, is comprised predominantly by pelagics and to a lesser extent reef species. A significant proportion of the total catch is illegal and unreported (15, 16), with large losses in revenue to the Indonesian economy from foreign fish stealing estimated to exceed USD 4 thousand million (Indonesian Government Minister Sarwono, pers. comm). Massive recent increases in aquaculture, mostly of shrimps (and to a lesser extent reef fish and lobster) in coastal ponds, and *Tilapia* in lakes and inland waters, supply increasing local demand and also contribute to the live fish trade to Hong Kong, China and Japan. At present, fish mariculture is largely dependent on capture of wild stocks for grow-out, although hatcheries are being developed (1).

Secondary and service industries, including international tourism, are of growing importance. Tourism was increasing at 5% annually from 1987 – 1995 in the Philippines (14), however kidnap and murder, growing civil unrest in Mindanao and in parts of Indonesia, global terrorism and recent disease outbreaks (Severe Acute Respiratory Syndrome, SARS), have caused a major decline in international tourism. This may be exacerbated over the next several years, at least to 2005, by the unstable global situation.

The major export earners include commercial exploitation of natural resources – particularly fisheries, aquaculture-mariculture, oil palm and other forms of plantation agriculture, and mining (13, 14). Much of the exports (and imports) are transported by ship. The Makassar Strait and Sulawesi Sea form a major oil tanker route (the ULCC route)

between Japan and the greater Pacific Ocean and the Indian Ocean-western Asia-Europe, with attendant risks of collisions and spills (17-19). There is already significant offshore oil and mineral exploration, with potential for substantial expansion in coming decades (19, 20).

Governance

The 3 nations are all constitutional democracies. Not one of the 3 national capital cities or major political centers is located within the Sulu-Sulawesi Sea area, and much of the political life is focused in the provinces, cities, towns, and villages. The area has various forms of traditional land ownership customs and systems of natural resource use, e.g. 'Sasi' in Indonesia.

With their neighbors, the 3 nations form part of the Association of South East Asian Nations (ASEAN), with strong multilateral links at political and trade levels. The Philippines, Indonesia, and Malaysia are also signatory to most of the key international conventions relevant to international waters issues, and have enacted various national laws and regulations (1), having ratified the: Convention on Biological Diversity (CBD); Convention on International Trade in Endangered Species (CITES); Ramsar wetlands convention; United Nations Framework Convention on Climate Change (UNFCCC); and World Heritage Convention.

The Philippines and Malaysia have also ratified the UN Convention on the Law of the Sea. The 3 nations have sovereign rights to the 12 nautical mile limit and have also declared 200-mile Exclusive Economic Zones. The Philippines and Indonesia unilaterally use the 'Archipelagic Doctrine' to define their territorial waters.

STATUS OF INTERNATIONAL WATERS

The international waters environment and socioeconomy of much of the Sulu-Sulawesi Sea are already under severe threat, with likely further deterioration (Table 1), driven by strong, complex and expanding linkages among freshwater shortage, pollution, global change, fisheries and habitat loss.

Freshwater Shortage and Pollution

Reliable access to potable water is a major food security issue, affecting millions of people in the Philippines and Indonesia (2). In 1990, only 35% of Indonesia's urban

Table 1. Global International Waters Assessment for Sulu-Sulawesi Sea (1). Subregional task-team assessment of environmental and socioeconomic impacts, under present conditions and the predicted future scenario for 2020, in key areas of concern (listed in descending order of severity of impacts; where 0 - no known impact, 1 - slight, 2 - moderate, and 3 - severe (see <http://www.giwa.net> for details).

International Waters Concern	Environmental score present - 2020	Economic score present - 2020	Health score present - 2020	Other social and community score present - 2020
Unsustainable exploitation of fisheries	3 - 3	3 - 3	3 - 3	3 - 3
Habitat and community modification	3 - 3	3 - 3	2 - 3	3 - 3
Pollution	2 - 3	2 - 3	2 - 3	2 - 3
Freshwater shortage	2 - 2	2 - 2	1 - 2	1 - 2
Global change	1 - 1	1 - 2	1 - 1	1 - 2

population and 33% of the rural population had access to safe water supply, and between 1990 and 2020, the demand is expected to increase by about 220%. With the sharply increasing needs for irrigation, safe drinking water, industrial water, energy, and other uses, the demand on water resources has increased rapidly. The relevant legislative instruments are inadequate for dealing with the current complex issues related to water abstraction, pollution and river basin management (1). Sewage treatment is superficial at best in many areas, including major urban centers, with raw and/or primary treated sewage discharged directly into water courses. Total emissions of organic water pollution have increased rapidly in Indonesia and Malaysia from 1980 to 1993, whereas in the Philippines, emissions have remained relatively stable (14, 21, 22).

Agricultural pollution is widespread, through leaching of fertilizers and pesticides into watercourses, massive loss of soils following land clearing and forestry, and increasing aquaculture activities. Environmental impacts from suspended solids, the result of extensive deforestation in many of the > 300 watersheds (23–25), are compounded by high rates of erosion, and siltation rates among the highest on earth. In the Philippines, estimates suggest c. 1 billion m³ of sediment are lost to coastal waters annually (26), carrying high, though unquantified, loads of particle-bound nutrients, impacting on coastal habitats of seagrass beds and coral reefs. High threat sites include much of the northern coast of Mindanao, several smaller areas of N Sulawesi and N Borneo (Sabah, Malaysia) and much of S Luzon (26, 27). By contrast, logging was halted on Palawan (Philippines), through effective implementation of legislation in the early 1990s, providing a major reduction in sediment loss from the catchments and much needed protection for the fringing coral reefs and other coastal and marine habitats (A. Alcala, pers. comm.) (1).

The 3 nations are adopting water pollution control standards similar to those in developed countries. However, formal regulation has been greatly hampered by the absence of clear and legally binding regulations; limited institutional capacity; lack of appropriate equipment and trained personnel; and inadequate information about emissions (28). Indonesia began formal regulation in 1992 (14, 29), with the establishment of maximum allowable volumes and concentrations (in kg tonne⁻¹ of output) for emissions of BOD and other water pollutants from 14 broadly-defined industrial sectors (e.g. textiles, wood pulping) (28, 29). Although self-reported BOD emissions are now mandated by law, reporting was extremely sparse until recently. Yet, despite weak or nonexistent formal regulation, there are many clean industrial plants. However, there are also many plants that are among the world's most serious polluters (28, 29). Among external sources of pressure, community action, or informal regulation, emerged as a clear source of interplant differences, while local income and education proved powerful predictors of the effectiveness of informal regulation (14, 28, 29). In the Philippines, the Department of Environment and Natural Resources (DENR) is introducing a public disclosure program, modeled on Indonesia's program (14).

Despite these and other improvements in regulatory interventions, the environmental and socioeconomic prognosis for the next 20 years (to 2020) is for increasing impacts to the environment, economy, health, and other social and community aspects from freshwater shortage and pollution issues (Table 1). With the rapidly-growing populations, addressing water security alone in an era of global change is

a major challenge, and urban sewage, river and coastal aquaculture projects, among a multitude of other pollution sources, are also growing rapidly, with insufficient intervention, regulation or enforcement.

GLOBAL CHANGE

The linkages between freshwater shortage, habitat loss and climate shifts may be developing through increasingly large ENSO fluctuations since the 1980s (1), affecting the onset and strength of the monsoons and producing flooding in some areas and drought in others. Predicted future changes in frequency and intensity of ENSO are expected to affect further the timing and strength of typhoons (30), floods, and droughts. ENSO fluctuations, notably during mid-1998 and 2002, caused elevated sea surface temperatures (SST) in much of the Sulu-Sulawesi Sea up to 2°C above average, as documented by NOAA/NESDIS 'hotspots' satellite imagery (31). This triggered extensive coral 'bleaching' and death in worst affected reefs (32–37), with substantial economic costs, not least from flow-on effects to fisheries (38).

UNSUSTAINABLE EXPLOITATION OF FISHERIES

About 70% of Philippine coral reefs are heavily overfished, producing < 5 tonnes (t) km⁻² yr⁻¹, with clear indications of 'trophic overfishing' (39, 40), in comparison with the remaining 30% of reefs which produce of the order of 15 – 20 t km⁻² yr⁻¹ (41). At species level, many of the more than 2500 species of fish, crustaceans, echinoderms, and molluscs are heavily overfished using a large variety of different gears and methods (15). A significant increase in effort in the pelagic fisheries, with more than 500 boats working from the Indonesian waters alone, has caused severe overexploitation of sharks, tuna, bill-fish, and other pelagic species. These pelagic species represent some 80% and 60% of the total production of N Sulawesi and E. Kalimantan, respectively (15). Sharks are also caught as by-catch in trawl fisheries and tuna long-line fishery.

Poison fishing for demersal reef fish, to supply the live food fish trade for Hong Kong and China and international aquarium trade, has burgeoned since the 1990s. Fish were collected initially using potassium cyanide or sodium cyanide and more recently also using poisons derived locally from plants (42–45). Prices have increased, with prime live reef fish worth USD 100 kg⁻¹ (46, 47), but CPUE has declined sharply. The marine aquarium trade is an international, multimillion dollar industry with 36% of the global trade coming from SE Asia (World Conservation Monitoring Center Convention on International Trade in Endangered Species WCMC-CITES database). Between 1996 and 1999 the share of the United States ornamental fish market coming from SE Asia increased from 67 to 78% (US Fish and Wildlife Custom declarations, unpubl. data). The current harvesting practice of the trade is unsustainable and is now among the most threatened of all fisheries (26). The cost to Indonesia from cyanide use is of the order of USD 46 million annually, threatening annual economic benefit from its reefs is of the order of USD 1.6 thousand million (26). The economic benefits for fishers are also minimal. In the Philippines, fishers who supply the aquarium trade typically earn only about USD 50 month⁻¹ (6). Less destructive techniques such as net capture are on the rise as a result of retraining efforts and new accreditation schemes, e.g. for



Large beds of staghorn coral *Acropora* with a conspicuous lack of reef fishes, following bleaching and poison fishing, Sulawesi Sea. Photo: L. DeVantier.

supply to aquarium trade, by the Marine Aquarium Council, but they have not yet overtaken cyanide fishing as the practice of choice (26).

There is also widespread use of explosives (reef bombing-blasting) (48–51), attributed to increasing competition among fishers and corresponding declines in catches. Virtually all of the much-diminished catch, including turtles, sharks and even whales, is kept and eaten by local fishermen. The only significant discards occur from the foreign fleets targeting tuna, swordfish, and other pelagics, shrimp and squid—notably shark carcasses, discarded after removal of their highly-valuable fins (52, 53).

The historical fisheries data indicate that in the 1950s some 30 000 t of fish were taken, mostly perch-like species, but including other finfishes, sharks and rays, molluscs and crustaceans. This tonnage increased rapidly to the mid-1970s, with some 450 000 t taken in 1975. Since then the total annual average catch has fluctuated between some 400 000–500 000 t (54). The Philippines Department of Agriculture statistics suggest that yields of some species have continued to increase, but that CPUE has declined steadily, suggestive of 'ecosystem overfishing' (39, 40, 55). A similar situation exists for some Indonesian Government statistics of Maximum Sustainable Yields (MSY), in part related to different assessment criteria and areas (15). At present neither status nor future viability of the fisheries are well understood. This is largely related to insufficient and inaccurate statistics, leading to a significant degree of skepticism among many fishery scientists in relation to government projections. For many fisheries, their status may be summarized as being: Illegal, Unreported, and Unregulated (IUU).

There are important gaps in both the biological and socioeconomic data, particularly in relation to commercial connections among population centers in terms of resource extraction, traditional village engagement with the marine environment, and the extent to which police and military are involved in resource extraction, both legally and illegally (15). The lack of data notwithstanding, mounting evidence from the Sulu-Sulawesi Sea and elsewhere has changed the once widespread belief that reef and other fisheries were virtually inexhaustible. In fact, there has been major loss of production and serious adverse 'cascading' effects to other components of the ecosystems (55).

Fisheries stocks, and the habitats that support them, are clearly in urgent need of careful stewardship (an ecosystem-based management approach), if their sustainable future utilization is to be assured. This will primarily require a high degree of local intervention and community-based support, effective enforcement of fisheries regulations (56, 57), and also reliable stock assessment and monitoring. The destructive methods, which deplete both target and nontarget species alike, and destroy the habitats on which the fisheries are based, must be controlled, requiring improved regulation, awareness and enforcement.

HABITAT LOSS

Terrestrial, coastal and marine habitats of the Sulu-Sulawesi Sea and their constituent species are under immense pressure (Table 1). Overall, greater than 80% of original vegetation cover

has been lost in most of the Philippines, with some 40 – 60% loss in the Malaysian (Sabah) areas of Borneo (26). More of the original forest cover remains in Indonesian E Kalimantan and N Sulawesi. Overall, some 60% of Borneo remains forested, although lowland forests are under particular threat from drought and fire impacts (e.g. 1997 ENSO) (58) and at least 30% of plant species in E Kalimantan have been lost through mechanized logging, notably for the highly valuable dipterocarps, with subsequent conversion to agricultural land and plantations (K. Kartawinata pers. comm.) (58). On Negros (Philippines), the 50% of original forest that remained in the 1930s has been reduced to 4% today (1). The surface area of marshes, swamps, riparian belts and forested river catchments has been reduced significantly (> 30%) in the past century, notably in areas of Mindanao, Negros, Cebu, E. Kalimantan and Sabah and some of the small islands of the Sulu Sea and Visayas. Loss of cover has contributed to severe levels of suspended solids in rivers and coastal waters, and burial – smothering of coastal habitats (3, 11, 13, 23, 26).

Major changes have occurred in freshwater habitats and their natural species complement from introductions (e.g. Tilapia and African catfish). In Indonesia, at least 60 of the 1400 freshwater fish species are threatened with extinction. In the Philippines, at least 26 of the 230 freshwater species are similarly threatened, whereas in Malaysia some 14 species of a total of 449 freshwater fish species are threatened (59). Some 60 – 80% or possibly more of the mangrove resources in the Philippines has been lost (60). In Indonesia, up to a million ha of land, mostly mangrove forests, were allocated by the government for the shrimp hatchery industry in the 1980s – 1990s, with substantial international donor support. By 2001, ~ 70% of the shrimp farms had been abandoned, because the operators found them unsustainable due to the high concentrations of acid sulfates from the destruction of the mangrove habitat (1).

Destructive fishing, including blasting, *muro-ami* (reef breakage to drive fish into nets) and poison fishing has damaged or destroyed more than 70% of coral reefs. Up to 50% of Indonesia's 51 000 km² of reef have already been degraded, with 85% threatened by human activities, which include coastal development, overfishing, and marine-based pollution (26). Most coastal coral reef areas, particularly those fringing the northern Sulu Sea and those separating the

Sulu and Sulawesi Seas, are at a high level of threat from overfishing. Similarly, high levels of threat exist for destructive fishing, focused particularly around Palawan, other Philippine islands, and NE Sabah. As the situation worsens, fishers resort to use of all methods to catch the remaining fishes, indicative of Malthusian overfishing (40, 55).

Overfishing and destructive fishing have caused major changes in population structures and/or functional group composition (e.g. coral reef fishes) significantly affecting ecosystem services (e.g. reef fisheries, mangrove resources). Exact figures are difficult to gauge, however, because of the paucity of long-term monitoring data. Efforts to improve existing data are continuing, particularly in areas like Bunaken National Park (61), but the damage being done outside PAs is likely far worse than that which occurs within view of park officials and police.

The Sulu-Sulawesi Sea has experienced significant loss or fragmentation of forest cover, riparian vegetation, mangroves, seagrasses, and coral reefs. There is also severe resource depletion, e.g. forestry, mangroves, fisheries, including illegal take of marine mammals, turtles and giant clams (62), leading to major changes in community structure and ecosystem productivity and reduction in ecosystem services.

These impacts have led to conflict among resource users (57, 62), and serious economic and health issues in poor, subsistence fishing communities, those with the highest birth-rates ($> 4\% \text{ yr}^{-1}$), from reductions in animal protein. In many areas, fisher families' children are malnourished as most fish are exported and fish consumption has declined from c. $36 \text{ kg person}^{-1} \text{ yr}^{-1}$ to $24 \text{ kg person}^{-1} \text{ yr}^{-1}$, with a concomitant decline in local rice production in recent times (1, 11, 13, 36). There are few alternative options, particularly on the small islands (63), and the levels of poverty are such that many children are trapped into becoming fishermen. Significant economic impacts have occurred to local villagers from loss of mangrove habitats and strip mining in Mindanao and elsewhere. Major economic costs are accruing from loss and modification of coral reefs, which are of immense economic value. In SE Asia generally, fisheries alone are estimated to be worth some USD 2.4 thousand million yr^{-1} . Based on their value in food security, employment, tourism, pharmaceutical research and shoreline protection (26), the reefs of Indonesia and the Philippines provided annual economic benefits estimated at USD 1.6 thousand million and USD 1.1 thousand million yr^{-1} in 2002 (26). However over the next 20 years, human impacts, notably overfishing, destructive fishing and sedimentation could cost Indonesia and the Philippines some USD 2.6 thousand million and USD 2.5 thousand million, respectively.

THE CAUSAL CHAIN OF HABITAT LOSS

Immediate Causes

The key immediate causes of habitat loss in the Sulu-Sulawesi Sea include:

- inappropriate land-clearing for agriculture, urbanization, mining and industrial development, forestry and aquaculture affecting catchments, marshes, swamps, rice paddies, riparian belts and mangroves, notably in N Mindanao, E Kalimantan, E Palawan, Visayas Islands, S Luzon and Sabah (20–27, 58, 64);
- unregulated use of fertilizers and other chemicals in the

agricultural sector (21, 22, 28, 29);

- runoff of suspended solids, siltation and dredging affecting seagrass beds and coral reefs (many areas of the Philippines, notably N Mindanao) (23–26);
- coastal port and harbor developments, industrial infrastructure wastes and increasing shipping (17–19);
- silica mining and solid wastes affecting sandy foreshores (S Luzon, Mindanao and Sabah) (1);
- overfishing, destructive blast and poison fishing affecting reefs (much of the area) (39–55);
- trawling affecting soft-bottom habitats (notably Sabah) and mid-water trawling, drift-netting and other forms of pelagic fisheries (56, 57);
- species introductions (e.g. *Tilapia* in freshwater lakes and recently also to saline waters) (1, 59);
- climate shifts (31–38, 65, 66).

Intermediate Causes

The key intermediate causes of habitat loss are:

- lack of stewardship, inadequate implementation of policy and legislation, and lack of resources and capacity to execute the law, including enforcement (67–69);
- unresolved resource access issues (70, 71), including among local and foreign fishermen (62);
- inappropriate use of new and/or inappropriate technology, including materials used in destructive fishing (39–55);
- lack of education-awareness, conservation ethics and perceptions (1, 72);
- inadequate investment in scientific assessments and management (1, 55, 72).

Root Causes / Driving Forces

The key root causes are population growth coupled with extreme poverty, increasing market demand and economic growth. Population growth is impacting on migration, urbanization, lack of employment and poverty. These in turn place greater pressure on services from the environment, e.g. fisheries, and contribute to increased pollution, damage to habitats, illegal practices and corruption. Economics and market trends drive the burgeoning and unsustainable use of resources and also influence corruption and illegal practices.

FUTURE SCENARIOS: IMPLICATIONS FOR HABITAT LOSS

The human population is expected to increase at between $2\text{--}3\% \text{ yr}^{-1}$ (1, 11, 13), to ~ 50 million by 2020, with increasing urbanization. Large-scale agriculture and forestry continue to be developed by both national and international commercial operators, although large areas have already been cleared of original vegetation cover. The timber industry has traditionally suffered from mismanagement and corruption, and despite recent improvements, implementation of 'best-practice' agricultural and forestry management, such as the retention of buffer zones along watercourses, is rarely enforced and violations are common (1).

Exploitation of pelagic and reef fisheries is also expected to increase, with a shift from local (subsistence) forms of fishing towards commercial, high capital investment forms. The rapidly increasing coastal population, level of poverty, greater commercialization, decline in resources, lack of effective regulation and poor–nonexistent enforcement, is expected to cause significant future deterioration, with likely

severe socioeconomic hardship, particularly for the majority of the poor rural population (1, 41, 63). In the artisanal sector the demand for seafood has led to an increase in small-scale commercial fisheries. For example, in the Calamianes Islands (Philippines) the growth in the number of fishers is much higher than that of the agricultural or other sectors, because of the small land area available (63). By 2010, there is expected to be a 10–30% deficit in wild-caught fish production, to be supplemented by aquaculture. A 50% reduction in fishing effort will be needed to restore many fisheries to sustainable levels, particularly in the municipal coastal fisheries which at present are 90% artisanal and 10% commercial (15, 63). Carnivorous families of reef fish will not fully recover their pre-fished levels of biomass for 20–40 years after effective protection has been implemented, when 20–25 kg of catch may be taken from 1000 m² of reef area annually (equivalent to 20–25 t km⁻²; A. Alcala pers. comm.) (1, 15, 63).

Industrial fishing fleets are also expanding *via* private companies, joint corporations and state-owned enterprises (15, 73, 74), with an expected increase in illegal activities (63). The Sulu-Sulawesi Sea is a tempting target for illegal fishing activities, both by poor local fishermen and commercial fishers from throughout SE Asia and foreign fleets, many of which do not carry legal permits. Illegal activities have significant environmental and socioeconomic impacts (63, 71), although accurate data on the extent, number of vessels and their mode of operations are scarce (15, 73, 74). There are plans to expand aquaculture substantially, with potential for additional fragmentation/loss of coastal habitats.

International trade is expected to triple by 2020 (Chua, T.E., PEMSEA, pers. comm.), with major expansion of international shipping through the ULCC route. Overall, SE Asia produces about 3.5% of the world's crude oil and 2.5% of its natural gas (75), and oil spills could potentially affect oceanic and coastal habitats, mangroves and coral reefs. The 3 nations have taken some steps towards developing oil spill contingency planning, yet little spill control equipment is in place and implementation of emergency procedures is not well developed (1).

Potentially severe global change effects are expected from shifts in timing and frequency of ENSO (30), with likely devastating environmental and socioeconomic effects for coral reefs (31–38). These impacts are predicted to manifest through the synergistic effects of elevated Sea Surface Temperatures (SSTs) causing widespread reef bleaching and death (65), and changes in ocean alkalinity affecting reef calcification processes (66).

Progress in managing these multifarious impacts and threats is not expected to be sufficient to mitigate fully the damaging effects of population growth and the other driving forces (1). For example, at present, most habitats are only poorly represented in protected areas (6, 8), and of those, most are poorly managed. Only 4% of Philippine coral reefs are listed as being protected, yet most of these are being degraded at increasing rates from destructive fishing, sedimentation and pollution, and the lack of law enforcement (6, 8, 76).

Yet a considerable amount of expertise now resides in government, academia and nongovernmental organizations (NGOs), and with improvements in coordination and cost-effectiveness, particularly at central government levels, there are strong opportunities for future success. The rate of deterioration can be minimized with appropriate interventions, including those at multilateral, national, provincial, and local

government levels, and through the continuing concerted efforts of NGOs, provided these receive adequate political, fiscal and logistic support. Most importantly, the resource owners and users must be persuaded that long-term sustainability is a much better option than short-term gains made at the expense of irreversible damage to the environment (77–81).

POLICY OPTIONS

The foremost consideration is the trilateral nature of the Sulu-Sulawesi Sea, with 3 different national jurisdictions, many transboundary issues, and many national, regional and international (as well as the local and provincial) stakeholders. The Philippines, Indonesia, and Malaysia have adequate legislation to address most of the key issues and concerns raised in this review. These nations are parties to most of the key international conventions and treaties. What is currently in urgent need of improvement is trilateral coordination and capacity to apply the existing legislation and to review and amend the legislation to improve its functionality, particularly cross-sectorally (Chua T.E., PEMSEA pers. comm.).

Recently, the 3 nations have taken steps at local, community, provincial and national levels (1, 68, 69), including implementation of legislation, to provide a modern framework for sustainable resource management, and development of policies relevant to obligations under the various International Conventions. However, despite the ratifications, there has been insufficient progress to date in implementation and the resolution of related problems.

There are also difficulties in gaining strong trilateral government support for interventions, and considerable challenges remain in engendering and coordinating government support among the 3 nations and across the different levels; national, provincial, and local. A recently developed *Environmental Strategy for the Seas of East Asia* (19) provides many pertinent recommendations and solutions to these problems (Chua T.E., PEMSEA, pers. comm.). Better integration of ocean-related sectors in policy, with linkages among food security, poverty, natural resources, environment pressures, market forces and governance is required. Consolidation of national laws and multilateral agreements to encompass all sectors, with better coordination in management and much-improved enforcement, with ongoing and expanded community education programs, are also needed.

National and international surveillance strategies, with participation from all levels of government, NGOs and local communities may be the best way of bridging the gaps between formulation, legislation and enforcement of regulations (19). There are opportunities for better allocation and use of local and international funds, particularly in light of the rapidly changing global situation and changes in funding priorities (Chua, T.E. PEMSEA, pers. comm.). There are major opportunities for improvement in both the political situation, particularly at national levels in the Philippines and Indonesia, where initiatives to date have not proven cost-effective, and from private sector and national/international NGOs.

At the broadest policy levels, recommended options include: *Coordination and Integration:*

- improvement of trilateral integration to maximize effectiveness of obligations under international conventions and treaties (e.g. CBD, WHA, UNCLOS, MARPOL, Ramsar);

- improvement of national integration of central government agencies and departments, particularly in the Philippines and Indonesia, and with international donors, to enhance cost-effectiveness of interventions;
- improvement of coordination among different levels of government and with local communities to maximize effectiveness of interventions across these different levels.

Intervention:

- expansion of programs to address population growth and reduce poverty, including significant focus on alternative/additional income generation programs (AIG);
- expansion of programs of integrated catchment and coastal-zone planning and management;
- expansion of local conservation programs, particularly focused on improving co-management of, and further development of, protected areas; linked together with expansion of assessment programs for identification of critical areas for conservation of biodiversity and fisheries (e.g. through government agencies, academia and NGOs such as The Nature Conservancy, World-Wide Fund for Nature, Conservation International, World Conservation Union, and many others);
- expansion of training and education programs to build additional long-term capacity and awareness among government, academia, NGOs, and communities.

The Sulu-Sulawesi Marine Eco-region (SSME) approach being developed by WWF (11, 82), and partners provides a useful model for policy development and implementation. The approach is 2-pronged: Conservation planning in the long term; and implementation of immediate conservation actions in key sites. The SSME recognizes that immediate interventions should be implemented in 5 priority areas: *i)* biophysical and socioeconomic research; *ii)* establishment of a network of protected areas; *iii)* development of sustainable livelihoods; *iv)* information/education/communication; *v)* institutional capacity-building including establishment of intergovernmental mechanisms.

At smaller spatial scales, improved management and expansion of the PA network is crucial. In light of the strong linkages between habitat loss and land clearing and sedimentation, and overexploitation of fisheries, the ameliorative role of PAs cannot be overemphasized. For terrestrial PAs, the majority of parks are successful at stopping land clearing, and to a lesser degree effective in mitigating logging, hunting, fire, and grazing (83). For marine PAs, there are also strong benefits for habitat conservation and fisheries replenishment, although at present, insufficient resources for management and enforcement of fisheries and other regulations limit effectiveness. Where sufficient resources have been available, notable successes have occurred and useful lessons learned, e.g. Bunaken National Park (70, 71, 84–86). Several small community-based management initiatives have also proven successful at protecting coral reefs and facilitating replenishment of reef-based fisheries, e.g. Apo Island, Danjungan Island (77–81). Thus, several key examples of the successes, failures and lessons learned from previous attempts at improving management and expanding the PA network already exist. However, to date, despite good intentions by the relevant government agencies and NGOs, there has been insufficient development and implementation, largely because of the overemphasis on national-level, often ‘command-control’, management.

EXPANSION AND IMPROVED MANAGEMENT OF PROTECTED AREAS

Specific policy recommendations for improving the management and coverage of the PA network in the Sulu-Sulawesi Sea include (8, 72, 76, 87, 88):

- review the current administrative frameworks; design strategies to resolve overlapping legal authority and jurisdiction in PAs;
- ensure Environmental Impact Assessments are conducted prior to any development in or adjacent to PAs, and wherever practicable, maintain buffer zones and minimize all future development of land within and adjacent to PAs;
- develop both terrestrial and marine ‘corridors’ among PAs, in terms of maximizing habitat area, effective population sizes and replenishment;
- set aside as much as practicable (at least 20–30%) of PAs as ‘no take’ zones for biodiversity conservation and harvested stock (e.g. fisheries) replenishment;
- retain flexibility in management approach, recognizing the value of co-management through small-scale, community-based approaches involving local municipalities, e.g. Barangay in the Philippines, Desa in Indonesia, and larger scale internationally-supported management initiatives;
- conduct strategic assessment of human resource requirements, including day-to-day management, surveillance and enforcement on a case-by-case basis;
- establish/refine monitoring programs and re-evaluate research priorities to best address biophysical and socio-economic management concerns;
- design management plans that include identified source(s) of operational funding;
- work through ASEAN and other multilateral, international agencies and organizations to develop joint programs, including innovative sources of ongoing funding;
- identify which PAs are working and which are not, and why, and disseminate successful case histories of management, e.g. Bunaken National Park (84–86).

Co-management

Co-management offers flexibility and can strengthen service delivery for conservation management. In a major boost of support for decentralized co-management of Indonesia’s National Parks, the Ministry of Forestry, in 2002, announced its support for the establishment of site-specific co-management forums for all National Parks. In the related case of the Philippines (37), Gloria Macapagal - Arroyo, the President of the Philippines noted in an address to the Second International Tropical Marine Ecosystem Management Symposium, 2003:

A significant Philippines national strategy is devolving management responsibility to the municipality and ‘barangay’ level under the Local Government Code passed by Congress in 1991...When communities are given the responsibility of managing their own resources with a little help from government and scientists, the damage to the reefs can be reversed...The Philippines Government is increasing sustainable management assistance to people who have a large dependence on these reef resources.

Improved management and expansion of the PA network is, however, only one of a suite of possible policy options that

might be used to achieve habitat conservation and fisheries management objectives (39–41, 55, 89). Other options in relation to fisheries include licensing and quota systems, closed seasons, size and catch limits, the effective development of which rely on a sound information base, effective surveillance and policing over broad areas. The information base needs to be founded in an improved understanding of the population biology of the target species, synecology of the supporting habitats and issues of ecological scale and connectivity in relation to replenishment. Many of these target species have distribution ranges extending outside the Sulu-Sulawesi Sea, with additional significant opportunities for international scientific collaboration and information-sharing.

CONCLUSIONS

When effectively implemented and managed, a fully integrated network of protected areas can play a key role in minimizing future habitat loss and restoring harvested stocks. In addition to a high degree of support from local communities, success will require effective enforcement, particularly of poaching and fisheries regulations, and reliable biodiversity and harvested stock assessment and monitoring. Full accounting of the value of ecological services from protected areas requires not only the accurate assessment and monitoring of biodiversity, harvested stocks and associated welfare of local populations. It also requires consideration of changes in ecological resilience, increased size and abundance of focal species within reserve boundaries, emigration of target species from reserves to adjacent areas, and behavioral responses of harvesters to spatially explicit closures (55, 89). Such analyzes are in their infancy, and are only now beginning to be undertaken globally. Nonetheless, most available data do support the effectiveness, efficiency, equity, political feasibility and implementation capacity of protected areas in mitigating both habitat loss and overexploitation. Without doubt, Sulu-Sulawesi Sea is a global priority area for immediate conservation initiatives. The Sea, with neighboring Indonesian Seas and the South China Sea, lies at the center of the world's tropical biodiversity, and is surrounded by rapidly growing populations and rapidly deteriorating ecosystems. Most of the impacts, their root causes and the policy options discussed herein are also highly relevant and applicable to these neighboring areas. The continuing challenge of gathering the necessary local, national and international, transboundary cooperation necessary for the sustainable development of this critical region is great, but not insurmountable.

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