Meso-scale Transboundary Units for the Management of Coral Reefs in the South China Sea Area

M.C.A. Ablan, J.W. McManus, C.A. Chen, K.T. Shao,
J. Bell, A.S. Cabanban, V.S. Tuan and I.W. Arthana

Abstract

Local communities and local government units are recognized as the primary stakeholders and participants in the management of coral reef resources and the primary beneficiaries of small-scale fishing activities in the nearshore areas of the coastal zone. The issues relating to the management of the coastal zone are multi-faceted and some issues are largely intertwined with national policy and development goals. Thus, national governments have jurisdiction over these nearshore coastal resources to harmonize policies, monitor resource use and provide incentives for sustainable use. However, the natural boundaries of these reef resources, the processes that support reef ecosystems, and the local or national affiliation of the people who benefit from them may transcend the boundaries of the local and national management units. Therefore, efforts to arrest the decline in fish catch and loss of biodiversity for reefs require management interventions and assessment activities to be carried out at varying scales. In Southeast Asia, some aspects of reef and reef resources management — particularly in deciding the allocation of catch among competing fisheries, development of sustainable harvest strategies, use of broodstock for restocking or stock enhancement programs, protection of nursery and spawning areas, designation of systems of marine protected areas, and the identification of representative, adequate and comprehensive areas for biodiversity conservation in the region — may require the definition of larger management units. At the regional level, multi-country initiatives will need to define units for the transboundary management of resources. The use of large marine ecosystems (LMEs) to identify and manage fisheries resources may be a starting point; however, given the relatively sedentary nature of coral reef-dwelling and reef-associated organisms compared with other pelagic and demersal species, meso-scale transboundary units within the LMEs have to be defined. This paper provides suggestions for transboundary management units for coral reef and reef-associated resources in Southeast Asia based on information from genetic structures of model organisms in the region. In addition, specific reef areas are identified, which may be important beyond their national boundaries, as potential sources of recruits.

Introduction

Much of the biodiversity and reef fisheries resources in Southeast Asia are unlikely to survive without active management. Coral reefs of the region are the most threatened with more than 80% at risk primarily from coastal development and fishing-related pressures (Bryant et al. 1998). Millions of coastal dwellers rely on reef resources for food and livelihood. As economies continue to grow and demands on the environment multiply, degradation and unsustainable use of this resource also increase.

Coastal communities in Southeast Asia are heavily dependent on fisheries. Catch from the reef fishery is estimated to comprise up to 20-25% of the total production from marine fisheries in countries like the Philippines and Indonesia (McManus 1997). Longhurst and Pauly (1987) have documented the occurrence of overfishing in east Malaysia, the Philippines, Vietnam and southern China. Reports show that the maximum sustainable yield (MSY), the limit reference point beyond which immediate and substantial action should be taken to protect harvested stock (Caddy and Csirke 1983), has already been exceeded for demersal (Silvestre et al. 1987), pelagic (Dalzell and Ganaden 1987; Trinidad et al. 1993) and reef fisheries (McManus and Meñez 1997) in the Philippines. Similar cases occur elsewhere in the region but are less well documented. The situation is apparently the same in Vietnam (Long in press) and eastern Malaysia (Abu Talib et al. in press) as growing populations turn to fishing as a source of livelihood.

Aside from being unsustainable, overfishing in the region has implications for species diversity and abundance for both pelagic (Christensen 1998) and reef fisheries (McManus 1992). Biodiversity loss due to harvest is apparent in the local-scale extinctions of reef-associated species such as the sea urchin *Tripneustes gratilla* (Talaue-McManus and Kesner 1995) and the giant clams *Tridacna derasa* and *Tridacna gigas* (Meñez et al. 1997).

Reef Connectivity and Implications for Management

Conceptually, rehabilitation and sustainability of a reef subject to intense fishing pressure hinge on the availability of new recruits and their success in replenishing resources removed from a reef. Eggs of most reef organisms are fertilized externally, and the majority have a larval phase when the larvae drift or swim for several days through the ocean. Resource managers need information on the dynamics of the source and eventual sink of recruits to design marine reserves, estimate the potential contribution of restocking to rehabilitation efforts, understand mechanisms that maintain biodiversity and maximize gains from a fishery. An area which is highly dependent on another area has to be managed differently from one that is primarily self-recruiting (Tuck and Possingham 2000). Connectivity among reef systems may lead to situations where different local or national groups harvest the same stock of resources. Thus, management regimes in one area may be ineffective because of competing uses of the resource elsewhere. Such connec-tivity also has implications for the vulnerability of sink reefs, when the relative sources which supply recruits experience massive damage.

There may be a disparity between boundaries of reef resources and the jurisdictional limits of resource managers. The natural boundaries of reef resources, and the processes that support these ecosystems, are defined by the physical structure of the reef, the distribution of particular species of interest, and the variable scales at which processes and interactions that support the system operate. However, management boundaries usually correspond to existing political and administrative systems. There is always a possibility that management goals may be inconsistent among different areas and at different scales. This discrepancy between boundary definitions and management goals requires an approach where management interventions and assessment activities are carried out from the local to the regional scale.

In Southeast Asia, very little is known about the source and sink dynamics of recruits that enter reef areas. In spite of this, resource managers in the region acknowledge the need for regional and multilateral management of coastal resources. This was articulated by the participants in the special session on marine protected areas at the International Coral Reef Initiative (ICRI) Regional Workshop for the East Asian Seas[1]. Participants to the regional workshop on the Sustainable Management of Coastal Fish Stocks in Asia[2] also recommended the identification of commonly exploited fish stocks, and the establishment of systems of marine protected areas, as some of the actions required to ensure sustainability of fisheries in the region. To date, management efforts for coral reefs are implemented at the local to the national levels, mostly guided by national programs. Bilateral and multilateral management programs have yet to commence although the agreement on the need for such action exists.

The term "transboundary management units" refers to resource areas beyond any defined management entity. The rest of this paper focuses more on the definition of units for management which are larger than areas covered by national boundaries.

Large-scale units for fisheries: the LME approach

Transboundary management initiatives for coral reefs will require an agreement on the definition of larger-scale units. A possible approach will be to adopt the large marine ecosystem (LME) boundaries defined for the management of coastal fish stocks. LMEs are regions with unique hydrographic regimes, sub-marine topography and trophically linked populations (Sherman 1986).

Four LMEs have been identified for Southeast Asia, the largest being the South China Sea, bounded by parts of China, Taiwan, Vietnam, Cambodia, Thailand, the Philippines, Singapore, Brunei, Indonesia and Malaysia. The Gulf of Thailand and the Gulf of Tonkin are two subsystems which open to the main LME. Two adjacent LMEs are the Sulu-Celebes Seas, bounded by east Malaysia and the island chains of Indonesia and southern Philippines, and the Indonesian or Banda Sea area which falls largely within the jurisdiction of Indonesia. A fourth ecosystem, the Straits of Malacca, to the west of the region is the southern part of the Bay of Bengal LME.

Meso-scale management units within LMEs

Case studies on the use of the LME approach have focused on the management of coastal pelagic species. Although LMEs may be a starting point to define transboundary management units for coral reef fisheries and habitat management, there is still a need to define smaller-scale units a step below the LMEs. This is because the primary target for management are reef-dwelling or reef-associated fish and invertebrate resources with adults that do not travel as widely as their pelagic counterparts. Transfers among reefs are mainly through propagules (i.e., eggs and pre-settlement juveniles) that remain in the pelagic phase for a few days to more than a month. Successful recruitment of these propagules on to a

[1] The International Coral Reef Initiative (ICRI) Regional Workshop for the East Asian Seas was held on 2-4 April 2001 in Cebu, Philippines. A special session on marine protected areas was held in which participants from South Korea, Japan, the Philippines, Vietnam, Thailand, Malaysia, Singapore and Indonesia discussed the need for more effective management of marine protected areas in the region.

[2] The International Workshop on Sustainable Management of Coastal Fish Stocks in Asia was held on 23-25 March 2001 in Penang, Malaysia. As part of the discussions, participants were asked to identify the major management actions required to ensure sustainable management of coastal fisheries at the regional scale.

reef is dependent on a number of local factors (Doherty 1991). Furthermore, reef ecosystems may not actually be as open as previously perceived (Cowen et al. 2000). Retention of reef larvae may be a high 85% for the leeward side and a low 35% for the windward side of small islands (Swearer et al. 1999).

Available data on species composition of fish communities present additional evidence of spatial heterogeneity in environmental conditions and also indicate spatial affinities of reef habitats (Shao et al. 1997; Vo 1998; Chen 1999). This is not surprising considering physical factors significantly influence both the composition of recruits that enter the system as well as the conditions for survival of the species. Veron (1995) used the high correlation between sea surface temperature and circulation patterns as the basis for analysis of the distribution of hermatypic corals in the Indo-Pacific region.

Genetics and the Identification of Transboundary Management Units

Genetic markers in conjunction with phenotypic characters may be a powerful means to identify spatial structures of reef populations. This is because the relationship between the marine ecosystem and the species that inhabit it is mediated by the genetic variability contained in the component species and the interaction of this variability with the environment. Climatic and oceanic factors that affect marine ecosystems will also affect the nature and organization of genetic information in species assemblages. Genetic changes within and between populations, in turn, can profoundly influence the distribution, abundance and persistence of marine species. Understanding of the complex interaction between the genetic material in marine species and the environment is rather rudimentary. Nevertheless, genes play an important and central role in shaping morphological phenotypes and behavior. Genetics also provide a biological basis for the identification of transboundary management boundaries because the persistence of genes through generations of populations identifies relationship.

Care must be exercised in deriving conclusions entirely from genetic data. Data on the biology and life history of a species have to complement genetic analysis. Genetic homogeneity between populations of different regions does not always signify that separate fishery stocks do not exist. Populations may not have been isolated long enough to establish differences in allele frequencies; or else exchange, however small, between individuals occurs and this is sufficient to maintain the same alleles between populations and contribute to genetic similarity between the fishery stocks (Grant and Waples 2000). Genetic analyses are generally 'one-way' tests of the hypothesis of heterogeneity and the null hypothesis of homogeneity is never proven.

Genetic structuring for model reef species in the South China Sea: transboundary reef groups

Evidence from a large-scale genetic study of 16 sites in six countries, namely Malaysia, Philippines, Indonesia, Vietnam, Taiwan and the Solomon Islands, suggests the occurrence of four major sub-provinces in the South China Sea and adjacent areas. This result is based on the observed genetic structuring in the populations of the damsel fish *Dascyllus trimaculatus* based on 12 polymorphic allozyme markers (Ablan et al. 1999). The groups identified are: (1) a West Pacific group to the east of the Philippines and southeast of Taiwan; (2) a north central group composed of northwest Taiwan, northern Vietnam and northwestern Philippines; (3) a southwestern group which includes southern Vietnam and the eastern coast of mainland Malaysia; and (4) a southern group which includes the south and central Philippines, east Malaysia and central Indonesia (Fig. 1). The study has been limited by the number of sites surveyed; however, the patterns observed are highly correlated with the general flow of surface currents in the South China Sea, and the results for two other reef fish species, the false Moorish idol *Heniochus acuminatus* and the six bar wrasse *Thallasoma hardwickii*, from the same study which are very similar to the patterns observed for *Dascyllus trimaculatus.* Although these two species were not sampled as extensively as the damsel fish and have longer larval duration, the combined results clearly present spatial structuring for three model species with different pelagic larval duration (Table 1). In addition, the convergence of three of the geographical groupings on the Spratly Islands suggests a high degree of genetic diversity at this location and provides further support for the potential importance of the Spratly Islands to the reef sources of several countries in the region.

If these patterns of affinity were to be considered as typical for reef areas, they will have some implications for current multilateral discussions on management actions for reefs and reef-associated fishery resources. Issues would include the identification of comprehensive, adequate and representative reef areas for biodiversity conservation in the region, the establishment of regional systems of marine protected areas, transfer and restocking of depleted populations and the management of fish stocks which are reef-dwelling or reef-associated at some point of their life history.

Examples of regionally important reef areas

Specific reef areas may be noted as being important beyond their national boundaries. Well preserved reef areas, areas which have been successfully

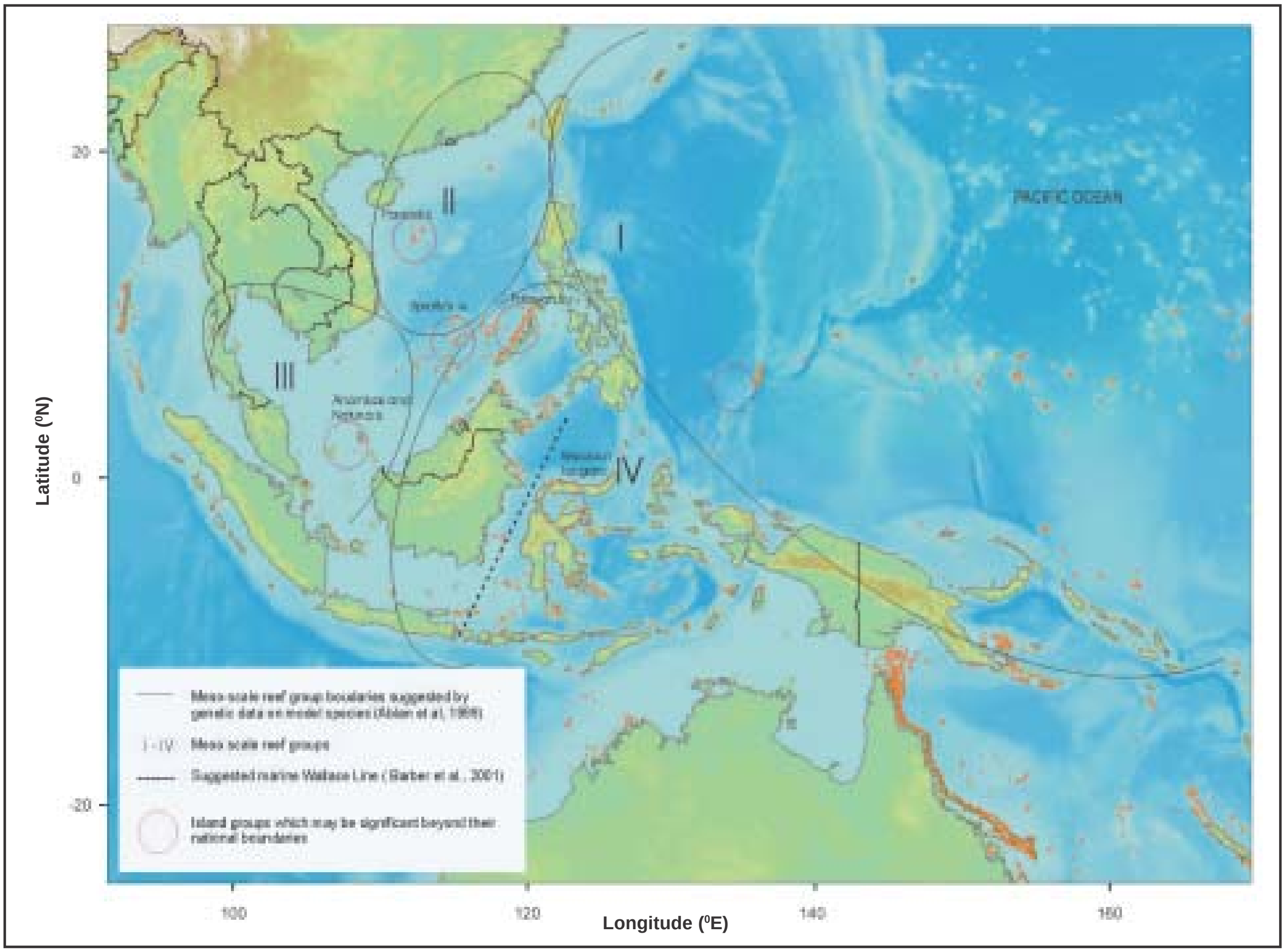

Fig. 1. Spatial structure based on genetic data from 16 populations of Dascyllus trimaculatus *in Southeast Asia.*

managed, or areas that have been subject to limited human intervention, may maintain natural ecosystems, which may be critical for the survival of some species, recovery of neighboring reefs and replenishment of the fishery.

In the South China Sea, large reef areas are found off the island of Palawan to the west of the Philippines, in the Spratlys and Paracel Islands and the Anambas and Natuna group to the northwestern side of Kalimantan (Burke et al. 2002). The reversing monsoons create wind and surface currents that may establish connectivity between oceanic shoal reefs and fringing reefs. This is true particularly on the windward side of the island groups where retention is less likely (Swearer et al. 1999). Strong currents transport water masses to and from Indonesia and the South China Sea through the southeastern sections of mainland Malaysia and Singapore (Meith and Helmer 1983) at speeds of at least 1 ms^{-1} (Wyrtki 1961).

The average duration of the pelagic phase is about 26 days for coral reef fish species (Brothers and Thresher 1985) and 7-10 days for coral larvae (Fadlallah 1983). For the Spratly Islands, the important ecological considerations have been suggested to include pelagic larval duration, timing of larvae release, favorable current patterns and associated oceanographic features, and the distribution of plankton masses during spawning seasons (McManus and Meñez 1997). The same authors present the possibility that the reefs in the islands

Table 1. Differences in some life history strategies of the species used as models to determine affinities among reef areas.

	Species		
	Dascyllus trimaculatus	*Heniochus acuminatus*	*Thallasoma hardwicki*
Habitat	Rocky coral often commensal with anemones and corals urchins	Deep protected lagoons, channels and outer slopes	Shallow lagoons and seaward reefs
Depth range	1-55 m	2-75 m	0-15 m
Occurrence	Highly territorial Occurs in small to large aggregations	Juveniles are solitary while adults occur as heterosexual pairs	Solitary
Pelagic larvae duration	21-25 days	30-34 days	44-47 days

may be a major source of recruits to reefs in Southern China, Vietnam, Taiwan, the Philippines and Malaysia. Using similar arguments, the Anambas and Natuna Islands and the outer reefs of Palawan may potentially be important to more than just one country.

The occurrence of meso-scale genetic structuring in coral reef organisms has also been reported elsewhere. For the mantis shrimp *Haptosquilla pulchera* in the Makassar Strait of the Indonesian Seas, Barber et al. (2000) suggest the possible existence of a marine Wallace line based on genetic data which differentiated populations to the east and west of the Makassar Strait. They have also identified the occurrence of unique fauna in Kepulauan Tongian. Populations from 11 reef systems of central Indonesia have shown highly distinctive genetic structures on either side of this line. These results, if typical for reef organisms, suggest further division of the Banda Sea LME to the west and east of the Makassar Strait.

Conclusion

Transboundary management units for coral reef ecosystems have to be identified to initiate multi-country initiatives that will halt and reverse the decline in reef resources in Southeast Asia. Definition of the geographical boundary of coral reef systems is not straightforward because this will depend on the boundaries of the physical structure of the reef, the distribution of particular species of interest and the variable scales at which processes and interactions that support the system operate. For a multi-country program on fisheries, previously defined LMEs may be used in the first instance, given the rationale behind the designation of these LMEs. However, meso-scale management units, a step below the LME, have to be defined for transboundary management of coral reef habitats and reef or reef-associated fishery resources. This is because recruitment of organisms that make up the reef and the reef-dwelling or reef-associated species of interest to the fishery is highly dependent on local factors. In addition, local retention of recruits differ between the windward and leeward reefs (Swearer et al. 1999) making some reefs more open to exchange than others within the same LME.

Data from genetic variation in populations of species are useful to identify the possible meso-scale transboundary management units. The data from unexploited reef species that were used as model organisms to explore patterns of affinity so far, suggest that the South China Sea LME may be divided into: (1) a West Pacific group to the east of the Philippines and southeast of Taiwan; (2) a north central group composed of northwest Taiwan, northern Vietnam and northwestern Philippines; (3) a southwestern group which includes southern Vietnam and the eastern coast of mainland Malaysia; and (4) a southern group which includes the south and central Philippines, east Malaysia and central Indonesia (Fig. 1). Genetic data from the study of the mantis shrimp *Haptosquilla pulchella* divides the Indonesian Seas LME into two areas to the east and west of the Makassar Strait. It is conceivable that smaller-scale divisions may exist within each of these sub-groups identified.

Aside from the identification of meso-scale transboundary management units, regional coral reef related management initiatives need to consider large reef areas which may be sources of recruits to countries beyond their national boundaries. The Palawan archipelago, the Spratlys and Paracel Islands, the Anambas and Natuna Islands, and the Kepulauan Tongian reef areas are a few of those identified as areas that are significant beyond their national boundaries.

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M.C.A. Ablan *and* **J. Bell** *are from the WorldFish Cente;* **J.W. McManus** *is from the Rosensteil School of Marine and Atmospheric Sciences, University of Miami, USA;* **C.A. Chen** *and* **K.T. Shao** *are from the Institute of Zoology, Academia Sinica, Taiwan;* **A.S. Cabanban** *is from the Borneo Marine Research Institute, University of Malaysia Sabah,Malaysia;* **V.S. Tuan** *is from the Department of Living Aquatic Resources,Institute of Oceanography, Vietnam; and* **I.W. Arthana** *is from Undayana University, Indonesia. The authors are project partners from six countries in the Population Interdepen-dencies in the South China Sea Ecosystems (PISCES) project coordinated by WorldFish Center and funded by the John D and Catherine T MacArthur Foundation.*