Proposal for a **SCOR Working group on the Coral Triangle**: the centre of maximum marine biodiversity

Background.

Tropical marine ecosystems are well known for their high biodiversity. Mangroves, seagrass beds, coral reefs, and adjacent pelagic communities depend on each other for the interchange of organisms, food and nutrients. They play a role in the protection of shorelines during storms and they are sources of income in local economies through fisheries, ecotourism, and mining (Adey 2000, Cesar 2000, White *et al.* 2000, Burke *et al.* 2002, Cesar *et al.* 2003, Hoeksema 2004). Coral reefs become damaged by unsustainable exploitation and increased siltation through river outlets, caused by land erosion. Corals as main reef-builders, have increasingly endured various kinds of illnesses and plagues. Climate change also appears to have impact. Since 1983, reefs have suffered from coral bleaching during periods of elevated seawater temperatures. Increased acidification of sea water will eventually hinder the production of calcium carbonate in corals and other reef-dwelling organisms with limestone skeletons. Because of their extreme high biodiversity, the protection of coral reefs is important for the conservation of global marine biodiversity. Even so, it is unknown which reef areas are most species-rich and it remains to be seen which reefs earn the highest priority in conservation.

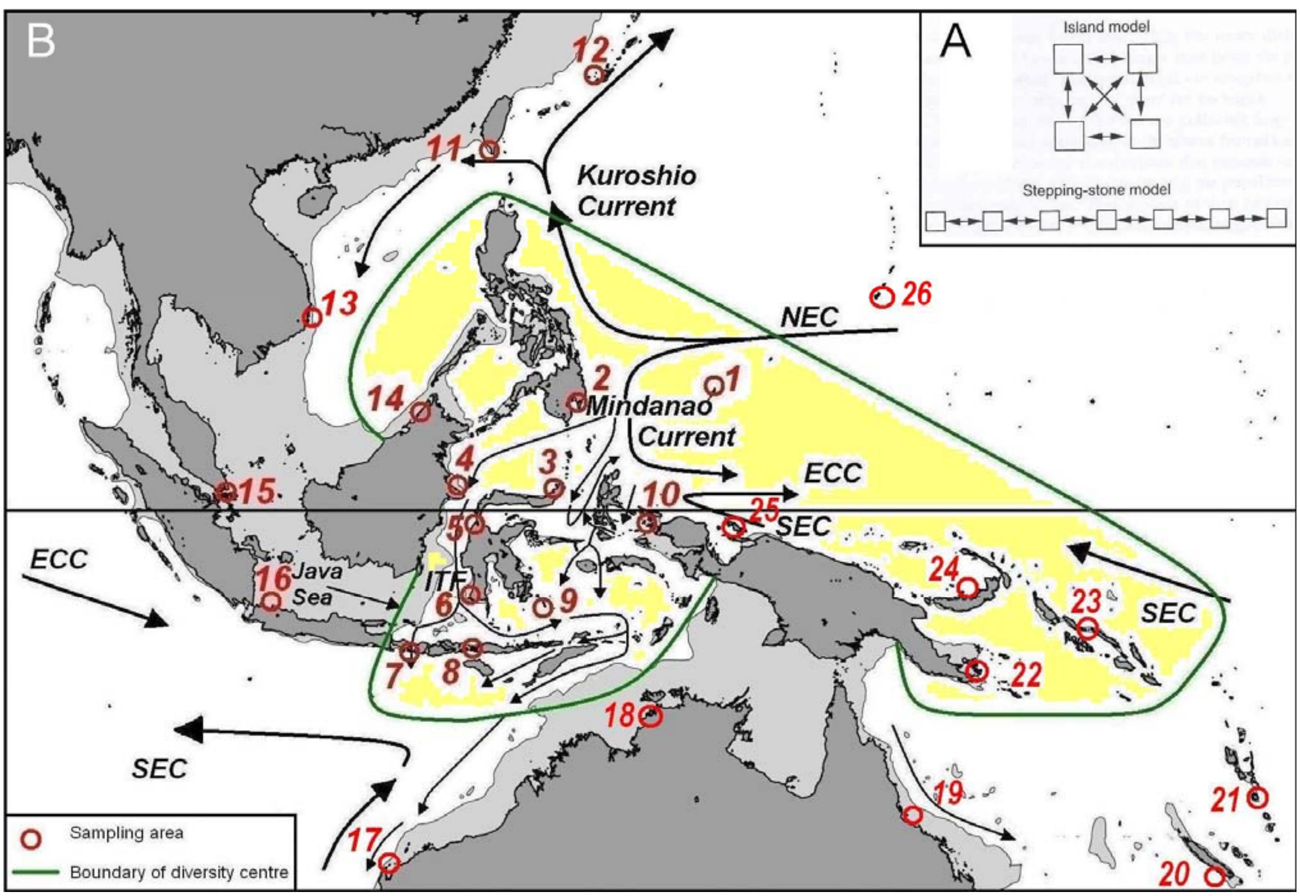

Fig. 1. A Coral Triangle model: a search for patterns and processes. A. Possible mechanisms of connectivity between populations (Palumbi 2003). B. The Southeast Asian - West Pacific centre of maximum marine biodiversity with hypothetical boundaries (Hoeksema 2007). Oceanic currents are indicated to show most likely major pathways of gene flow. Areas indicated in and outside this hypothetical Coral Triangle are candidates for data sampling.

The extreme species richness of reefs is predominantly resulting from complex species interdependencies. Reef corals and some other reef-dwelling organisms harbor algal symbionts (zooxanthellae). With the help of sunlight in transparent warm seawater, these algae are responsible for reef formation by limestone accumulation in corals. Corals and many other sedentary organisms, serve as food and hiding place to other organisms. Many host-symbiont relationships appear very specific. In order to study the evolutionary (phylogenetic) history of species associations, both the host and the symbiont species groups need to be known. Such studies require the molecular (DNA) analyses in order to reveal sibling species (look-alikes) and to indicate evolutionary inter-relationships (Gittenberger & Gittenberger 2005, Schiaparelli *et al*. 2005, Fransen 2007).

Coral reefs of the Indo-Pacific are more species-rich than Atlantic reefs. The world's highest concentration of marine species occurs in the Southeast Asian – West Pacific (SEA-WP) region, which has been dubbed 'The Coral Triangle', signifying the importance of coral reefs. The distribution ranges of species (especially endemic and endangered ones), is relevant for the design of marine protected areas (MPAs). However, due to a lack of data, it is unclear where the boundaries of this centre of maximum marine biodiversity are located (Green & Mous 2004, Hoeksema & Putra 2002, Hoeksema 2007). This delineation of the Coral Triangle has to be based on reliable species records. Observations of only benthic organisms are not sufficient since most marine species are also represented by a free-living phase (usually larvae) in the open water in between reefs (Paulay & Meyer 2006). The dispersal of reef organisms is largely determined by the duration of this free-living phase and by the direction and speed of currents.

Rationale: integration of taxonomic expertise and assessment methods

Knowledge on the position of the Coral Triangle will benefit from cooperation by specialists of various marine taxa and by physical oceanographers who know about past and present oceanic currents. At present, different assessment methods are used for marine biodiversity analyses. Although diversity patterns among various groups of marine organisms appear to show much congruence, there is little data to substantiate unifying conclusions. Many marine species show large geographical distribution ranges, especially if a high dispersal capacity is linked to a long-lived larval stage. Other species show very restricted ranges, due to a short larval stage or its absence (such as in brooding species). However, most reef-dwelling species show widespread (Indo-West Pacific = IWP) ranges, although range expansion was probably interrupted and maybe reversed during low sea level stands, such as during the last Glacial Maximum (Hoeksema 2007).

In order to get a better insight in Indo-West Pacific species richness patterns, marine biodiversity specialists need to cooperate in order to compare species richness patterns of various reef taxa. For some taxa, various assessment methods should be used to enable calibrations. Assessments of large taxa have as disadvantage that they are less reliable and nearly irreproducible due to unresolved taxonomies. Specimens of such taxa need to be deposited in reference collections. The use of presence / absence data is another method, which is mostly applied to smaller taxa (at genus or family level). Their assessments can done with little effort in a relatively short time.

Since present species range boundaries are maintained by gene flow, it is important to find species suitable for phylogeographic studies that indicate connectivity among populations. The outcome may support the design of networks of marine protected areas (MPAs), which not only conserve gene pools for areas surrounding MPAs (replenishing by spill-over), but also make MPAs themselves resilient in case local extinction requires the replacement by larval recruits from an upstream source.

Scientific background

For the designation of a network of Marine Protected Areas (MPAs) and for other conservation efforts, it is important to know which areas are particularly rich in species (Ferrier 2002, Allen & Adrim 2003, Green & Mous 2004, Briggs 2004, 2005), especially in endemic species that show relatively small ranges (Myers *et al*. 2000, Allen 2002, Roberts *et al*. 2002; Hughes *et al.* 2002, Beger *et al*. 2003, Mora *et al.* 2003, Myers & Ottensmeyer, 2005, Allen 2007). The biodiversity assessment approaches that are used to distinguish areas fit for MPA status, usually rely on data from areas that have been selected a priori for MPA destination. They are intended for local conservation efforts and do not give complete information for biogeographic comparisons of species richness between areas. They are supposed to be rapid and just produce species lists made by individual observers through a visual census to support species richness numbers as high as possible without supporting proof (such as voucher specimens, photographs). Such records may contain synonymies, different names for the same species, which inflates the species numbers but devaluates their quality. The observers in such biotic surveys are usually generalists who are trained in the identification of species, but they may not be able to solve taxonomic problems and publish on this.

Marine biodiversity assessments for scientific biogeographical studies serve to gain knowledge on the species richness of a selected area and to collect records for the analysis of individual species ranges. Families, genera, and other species groups that have undergone taxonomic revisions are ideal for use in surveys since synonymies have been minimized. Such taxa should be used a models (key taxa, exemplars, etc.) but have as disadvantage that they may not be completely representative.

Species diversity patterns may change as a result of Global Change, which may effect the outcome of assessements. Historical data on occurrence records are usually stored in museum collections. Species containing limestone skeletons are very suitable since they can most easily be preserved in dry condition. In order to find long-term changes in species composition, extensive collections per locality are needed. For the Coral Triangle itself no specific localities are known to show long-term changes. Examples of documented changes in marine biodiversity (in connection to sedimentation, pollution and dredging) are known from densely populated cities, such as Singapore and Jakarta, with a long history of sampling and monitoring (Hoeksema & Koh, subm, Meij *et al.* in prep.). Even if the present position of the centre of maximum marine diversity becomes more clear, very little remains known about its origin during the Cenozoic (Renema 2007).

Different assessment methods need to be compared for biogeographic and phylogeographic studies:

1. ATBI (= All Taxon Biodiversity Inventory) aims at giving an overview of as many species as possible in an area with maximum effort, including the use of many scientists and methods. This method may help to approach the real number of species present in an area. Not all species need to be identified directly in the case of morpho-species counts (Bouchet *et al.* 2002). Material is usually deposited in a scientific reference collection for further investigation.

2. RAP (= Rapid Assessment Program) or REA (= Rapid Ecological Assessment) aims at giving species overviews within a limited time frame of dominant key groups per area surveyed, such as reef coral species, reef fish, etc. (Werner & Allen 2000, Allen & McKenna 2001, McKenna *et al.* 2002, Allen *et al.* 2003). Since these taxa are represented by high species numbers (> 500), no precise estimate of the real species number can be found, depending on the time available. Records

of new species remain unclear unless material has been sampled for study by a specialist. Oherwise, the claims remain untested. There is a likely occurrence of false records, due to the use of synonyms. The reliability of the results depends heavily on the experience of the observers.

3. PAR (= Presence – Absence Records) aims at giving a complete overviews of species present and absent in a surveyed area. Model taxa of 50-100 species are used (genera, families) that have been taxonomically revised. Since species presence and absence records are obtained per sample unit within a surveyed area, statistically reliable species richness estimators can be given (with error margins). The specialized observer needs to spend much time per survey area (2-4 weeks) and preferably the same observer needs to complete the surveys for each area included in the comparison. Species records are represented by voucher specimens in reference collections and/or by photographic evidence. New species are rare since the model taxon has been taxonomically revised already, which minimizes the risk of overlooked species. This method is not commonly used (Hoeksema 1993, 1997, Hoeksema & Putra 2002, McKenna, 2006, Hoeksema 2007).

4. Phylogeography. Molecular methods using suitable genetic markers (e.g. micro-satellites) are used to map species boundaries and affinities between populations of selected reef organisms in different reef areas (Knowlton 2000, Benzie 2000, 2001, Lessios et al., 2001, 2003, Hellberg et al. 2002, Williams *et al.* 2002, Uthike & Benzie 2003, Chen *et al*. 2004, Froukh & Kochzius 2008, Kochzius & Nuryanto 2008, Timm *et al.* 2008). The sampling should be based on the direction of ocean currents and the position of continental shelves (Fig. 1). In addition to long-term changes in oceanic currents due to sea level fluctuations (Hantoro *et al.* 1995, Hantoro 1997), also seasonal variation in oceanic currents and salinity of the surface water might be relevant in order to explain present distribution patterns and connectivity (Wolanski 2001, Gordon *et al.* 2003, Fang *et al* 2005, Susanto *et al.* 2007, http://www.earth.columbia.edu/news/flash/itf2004.html).
Results so far indicate a major genetic distinction between populations at both sides of the Sunda shelf margin, separating west and east Indonesia from each other (Barber *et al.* 2000, 2002, Lourie & Vincent 2004, Lourie *et al.* 2005, Collette 2005, Knittweis *et al.* 2008, Kochzius & Nuryanto 2008). A design of MPA networks would benefit from information on species diversity, endemism and gene flow in relation to oceanic current patterns (Ablan *et al.* 2000, 2004, Beger *et al.* 2003, Palumbi 2003, Roberts *et al.* 2006).

Terms of reference
Within the proposed four year of existence, the WG plans to achieve results on

- integrating methods for coral reef biodiversity assessments
- integration of coral reef biodiversity research and conservation
- areas suitable for biodiversity assessments and DNA sampling for connectivity studies
- reef organisms that are suitable for connectivity studies
- genetic markers for organisms in phylogeographic connectivity studies
- oceanic currents and their seasonal variation at depths that are relevant for larval transport

Three meetings in the SEA-WP region in collaboration with local institutes and nature conservation organizations working on coral reef biodiversity management. Objectives are

- to develop an integrative research strategy in order to determine the boundaries of the Coral Triangle
- to present results on marine biodiversity, phylogeography, and relevant oceanic current patterns (past and present)
- to collaborate in fieldwork, to assist each other in sampling from various localities

- to assist in the organization of workshops in the SEA-WP region dealing with the identification of coral reef model taxa.

Publications in peer-reviewed journals using examples of various model taxa.

Time line

The meetings will be organized in conjunction with already planned symposiums and workshops. Proposed examples:

2009. World Ocean Conference, Manado, North Sulawesi, Indonesia.

2010. Second Asia-Pacific Coral reef Symposium, Phuket, Thailand.

2011. Opening of new building Coral Triangle Centre, Bali, Indonesia.

IOC/WESTPAC symposiums are very relevant for the region and may offer possible opportunities. The 7th symposium (2008) was in Kota Kinabalu, Sabah, Malaysia.

Prologue: open scientific meetings that completely or partly have dealt with coral reef biodiversity (non-integrative)

9th International Coral Reef Symposium, Bali, 2000. Relevant mini-symposiums:
- The East Indies Triangle of maximum marine biodiversity: Definition and origins
- Molecular phylogeny and population genetics in coral reefs
- Coral reef biodiversity: assessment and conservation

10th International Coral Reef Symposium, Okinawa, 2004. Relevant mini-symposiums:
- Biodiversity and diversification in the Indo-West Pacific
- The Coral Triangle: Global center of coral reef richness
- Connectivity in coral reef systems – scientific challenges and management consequences

1st Asia-Pacific Coral Reef Symposium, Hong Kong, 2006. Relevant mini-symposium:
- Investigating connectivity and meaningful scales for managing coral reef resources

11th International Coral Reef Symposium, Fort Lauderdale, 2008. Relevant mini-symposium:
- Biodiversity and diversification of reef organisms

1st World Conference on Marine Biodiversity, Valencia, 2008. Relevant session:
- The Coral Triangle: patterns and processes in marine species richness and habitat diversity

The SCOR working group

Many specialists on IWP reef organisms are based outside this region (where most of the old reference collections and libraries are). The SCOR working group should represent many nations and specialties (taxa). Meetings and workshops should preferably occur in the SEA-WP region in order to make information available to local scientists, NGO's, and park managements.

Nature conservation organizations, such as TNC since 1951 (The Nature Conservancy, at http://www.nature.org/), WWF since 1961 (World Wildlife Fund, at http://www.panda.org/), and CI since 1987 (Conservation International, at http://www.conservation.org/), should link to the SCOR working group by assigning their marine biodiversity and MPA specialists to SCOR meetings as associate members. TNC is establishing a Center (http://www.coraltrianglecenter.org/) at Bali in order to "generate knowledge on marine biodiversity conservation and on sustainable use of marine resources in the Coral Triangle, and to ensure that this knowledge is applied in on-site MPA management, in awareness and communication, and in policy". The results of the SCOR meetings should become available as technical information that can be applied to help in the development of monitoring protocols and content for training programs according to the latest scientific insights as effective management tools for biodiversity conservation.

The WG on the Coral Triangle may be able to link up with the Census of Marine Life's (CoML), Census of Coral Reef (CReef) http://www.creefs.org/. It also plans to link with EU FP6 network of excellence, the European Distributed Institute of Taxonomy (EDIT), Work Package 7 on Taxonomy for Conservation. http://wp7.e-taxonomy.eu/. Meetings will be announced via relevant e-mail lists.

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Co-chairs:			
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Dr. C.L. Villanoy	m	Physical oceanography	Marine Science Institute, University of the Philippines, Quezon City, Philippines
Dr. W.S. Hantoro	m	Climate change	Research Centre of Geotechnology (LIPI), Bandung, Indonesia
Dr. Marc Kochzius	m	Connectivity	University of Bremen, Germany
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Dr. Peter Ng	m	Crustaceans	Raffles Museum of Biodiversity, National University of Singapore, Singapore
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Associate members:			
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Dr. Lida Pet-Soede.	f	Coral Triangle	WWF-Indonesia, Bali, Indonesia
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Dr. Nicole J. de Voogd	f	Sponges	Naturalis, Leiden The Netherlands
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