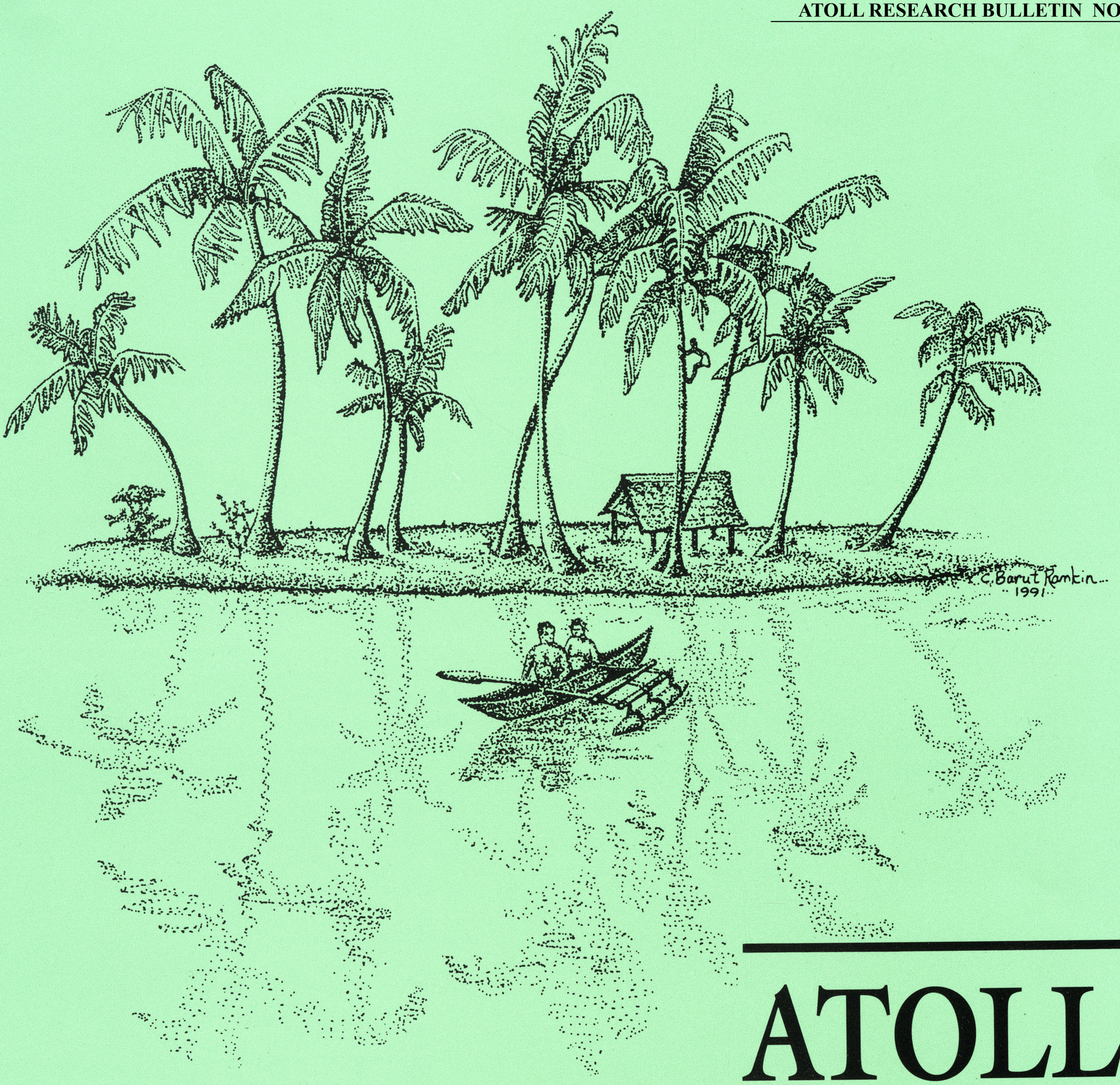
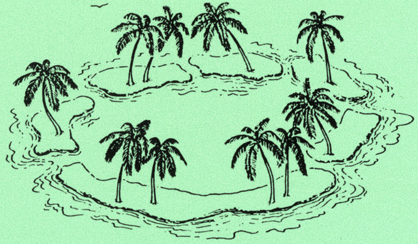
ATOLL RESEARCH BULLETIN NO. 590



ATOLL RESEARCH BULLETIN

BIODIVERSITY, RESOURCES, AND CONSERVATION OF BAA ATOLL (REPUBLIC OF MALDIVES): A UNESCO MAN AND BIOSPHERE RESERVE

Edited by
Serge Andréfouët



Issued by

NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C. U.S.A.
JANUARY 2012

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ACKNOWLEDGMENT

The Atoll Research Bulletin is issued by the Smithsonian Institution to provide an outlet for information on the biota of tropical islands and reefs and on the environment that supports the biota. The Bulletin is supported by the National Museum of Natural History. This issue is partly financed and distributed with funds from Atoll Research Bulletin readers and authors.

The Bulletin was founded in 1951 and the first 117 numbers were issued by the Pacific Science Board, National Academy of Sciences, with financial support from the Office of Naval Research. Its pages were devoted largely to reports resulting from the Pacific Science Board's Coral Atoll Program.

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FOREWORD TO THE SPECIAL ISSUE ON BAA ATOLL, A UNESCO MAN AND BIOSPHERE RESERVE

BY

SERGE ANDRÉFOUËT[1] AND M. SHIHAM. ADAM [2]

INTRODUCTION

The studies compiled in this volume result from various initiatives that converged in 2010 into the delivery of substantial new information on fisheries, sedimentology, and biodiversity for a specific atoll of the Republic of Maldives, namely Baa Atoll, also known as South Maalhosmadulu Atoll (Fig. 1).

Baa Atoll has been included since late June 2011 in the list of the UNESCO Man And Biosphere (MAB) Reserve. Achieving MAB status means that the atoll is characterized by local communities actively involved in governance and management, research, education, training and monitoring at the service of both socio-economic development and biodiversity conservation. This nomination largely results from the efforts of the Atoll Ecosystem Conservation (AEC) project, which has also channeled to Baa Atoll several studies related to climate change and island vulnerability, biodiversity, and fisheries. The AEC was launched by the Government of Maldives with support from the United Nations Development Program (UNDP) and Global Environment Facility (GEF). Besides Maldivian initiatives spearheaded by AEC and the Marine Research Center (MRC), this Baa Atoll volume results mainly from studies funded by the French *Foundation Pour la Recherche sur la Biodiversité* (FRB) in the frame of the Biodiversity of Indian Ocean Islands program. The study on the sedimentology of reef islands was funded by the Royal Society of New Zealand, Marsden Fund, and The University of Auckland.

The amount of information available now on Baa Atoll is matched by none of the other Maldivian atolls. Historically, coral reefs and atolls of the Maldives have been a major site of scientific investigation. Gardiner (1903) and Agassiz (1903) and subsequent expeditions provided data and theories that contributed to the foundation of coral reef science (Wallace and Zahir, 2007). Addu Atoll, the most southern atoll of the Maldivian archipelago, was the focus of several investigations reported in a previous Atoll Research Bulletin issue (Stoddart, 1966).

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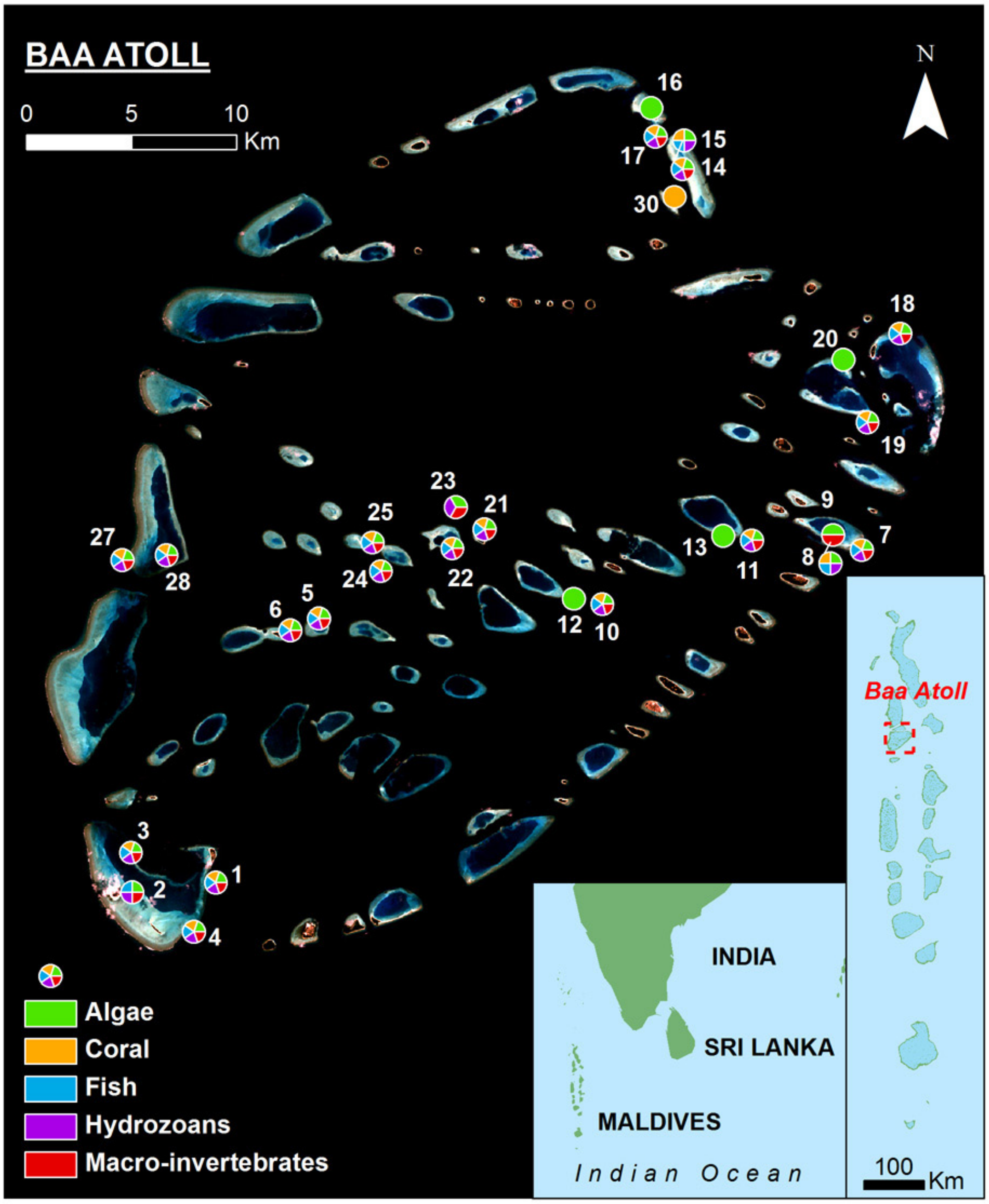

Figure 1. Map of Baa Atoll and position of the habitat and taxonomy sampling sites visited in May-June 2009. Pie-charts show the various taxa sampled in each station in May-June 2009.

In the modern era of coral reef research, however, Maldives have been somewhat neglected with few new taxonomic work (e.g., Benzoni and Pichon, 2007) and few functional studies on coral community dynamics (e.g., Lasagna et al. 2010). Impact of global warming, (with severe coral bleaching in 1998 and anticipated sea level rise), and natural catastrophes (tsunami) have triggered new data collection in various Maldives atolls (e.g., McClanahan et al., 2000; Zahir et al., 2006; Kench, 2011), but not as systematic as in Baa Atoll recently.

CONTENT OF THE BAA ATOLL SPECIAL ISSUE

This volume includes sedimentology, taxonomy, fishery, habitat mapping and conservation planning studies.

The opening paper by Kench compiles the results of the first systematic monitoring programme established to examine the morphological adjustment of Baa Atoll islands to physical forcing. It describes the physical environment of Maldives and Baa Atoll and the regime that has controlled reef island formation across the atoll.

This volume also includes taxonomic work and check-lists for corals (Bigot and Amir), algae (Payri et al.), hydrozoans (Gravier-Bonnet and Bourmaud), fishes (Chabanet et al.) and other macro-invertebrates (Andréfouët, Menou, and Naeem) from a field expedition carried out in May-June 2009. These new inventories, some for taxa poorly studied in Maldives, have modified species distribution knowledge at the scale of Baa, Maldives and the Indian Ocean, with new records (up to 113 for algae for instance) for Maldives and new records for the Indian Ocean. In addition to the collection of new taxonomic information, the sampling was coordinated to ensure that each taxa was inventoried in the same sites (Fig. 1) in order to obtain a comprehensive view of Baa biodiversity useful to test various conservation planning approaches. Indeed, spatial co-occurences of taxonomic lists, within exactly the same locations and habitats, are still seldom available. We found in previous studies that scattered data could be a limitation when testing new conservation approaches, and achieving a spatially coherent sampling was one of the goal of the Baa new data collection (Dalleau et al., 2010).

The processing of very high resolution remote sensing images yielded habitat maps that were used to infer maps of biodiversity distribution and propose a marine protected areas network meeting an exhaustive species representation conservation goal (Andréfouët,Rilwan, and Hamel; Hamel and Andréfouët). Although the process is straightforward given the current advances in conservation planning and tools, yet very few coral reef sites benefit from similar recommendations. For Baa Atoll, these propositions assisted with the choice of several new MPAs made by AEC and the Maldivian Ministry of Housing and Environment, and endorsed by the MAB listing.

The present compilation also includes a much needed central Maldives assessment of reef fisheries (Sattar et al.). Maldives should reach close to 800.000 visitors in 2011 and tourism in Baa is likely to increase with the new MAB status. Growing tourism and the demand for local reef fish, as well as local reef fish consumption, may balance the traditional focus on tuna fisheries towards reef fisheries. This sector of activity becomes a significant socio-economic component of the Central Maldives human population.

Two studies have also investigated the movement of reef fishes using two different techniques: tagging (Sattar et al.) and microchemistry (Criquet et al.). Both are preliminary studies that open perspectives for refining the choice of conservation areas using dispersal and movement information. Further work in Baa should, indeed, consider the monitoring of functional processes at ecological scales (connectivity, recruitment, etc.).

PERSPECTIVES

The value of systematic new data acquisition on various aspects of the natural history, ecology and sedimentology of a coral reef site is immense. First, this sets a reference in an age of global change for future monitoring. Describing now the actual richness and biodiversity of a fairly pristine site will be tremendously useful in future decades. Second, the inventory updates, and modifies substantially, biogeographic pattern in the region. Obviously, enormous gaps remain in the knowledge of Maldives biodiversity. Many taxa remain poorly sampled and additional and new inventories are justified. Third, island dynamics, taxonomy work, habitat maps and fishery data can be directly used to drive options for conservation planning. Planning new Marine Protected Areas is part of the MAB status agenda, and Baa now benefits from biodiversity-driven propositions that support the decisions that Maldives authorities might take in the future, this time using additional socio-economic information. In fact, the biodiversity-driven proposition in Hamel and Andréfouët matches well the selection of sites for new MPAs that has been made in 2009-2011. This assisted with the value of these choices.

Obviously these first steps do not necessarily fill the agenda of a perfect theoretical network required to meet coral reef conservation goals, both in terms of species and processes (Gaines et al., 2010). However, the addition of new MPAs in Baa Atoll (9 between 2009 and 2011) and the new MAB status achieved by AEC definitely mark tangible advances towards Maldivian reefs conservation. Further work should consider extending the network of conservation areas in Baa Atoll, but also to other atolls in Maldives. As a guideline, the work presented here provides a pragmatic approach that requires expertise (taxonomy, mapping) but very little new research. As such, information is cost-effective, site specific, timely and can be guaranteed. These are four criteria that should catch the attention of managers. In addition, the genetics data set collected during this project also contributes to biogeography and macro-ecology advances.

Beyond Maldives biodiversity conservation, the concerns on the conservation of Maldives, as a country, have grown tremendously given the projections on sea level rise. From a geological stand point, however, reef islands do not appear under threat with the current projections on sea level rise given the sedimentary and physical processes observed on Baa islands (see Kench's paper and references within). Nevertheless, from a human perspective, given the modern changes in island uses as well as changes in coral communities following coral bleaching events, climate change will likely influence the way Maldivians are planning their future. Vulnerability assessment will be needed, at a meaningful scale. In order to help decision makers, adequate fine atoll-scale maps and models, obtained from proper physical and sedimentological characterization, will be needed, as well as sustained monitoring of human uses and resources status.

ACKNOWLEDGEMENTS

We acknowledge the support of the French Fondation pour la Recherche sur la Biodiversité, Programme "Biodiversité des Iles de l'Océan Indien" and the Atoll Ecosystem Conservation project for making this volume possible. We thank all the contributors to the various biological and mapping data sets.

REFERENCES

Agassiz, A.
1903. *The Coral Reefs of the Maldives.* Memoirs of the Museum of Comparative Zoology, Harvard College, 29, 1-68.

Andréfouët, S., J.L. Menou, and S. Naeem
2012. Macro-invertebrates communities of Baa Atoll, Republic of Maldives. *Atoll Research Bulletin* 590: 125-142

Andréfouët, S., Y. Rilwan, and M. Hamel
2012. Habitat mapping for conservation planning in Baa Atoll, Republic of Maldives. *Atoll Research Bulletin* 590: 207-221

Bigot, L., and H. Amir
2012. Scleractinia corals of Baa atoll (Maldives): First checklist and overview of stony corals community structure. *Atoll Research Bulletin* 590: 67-83

Dalleau, M., S. Andréfouët, C.C.C. Wabnitz, C. Payri, L. Wantiez, M. Pichon, K. Friedman, L. Vigliola, and F. Benzoni
2010. Use of habitats as surrogates of biodiversity for efficient coral reef conservation planning in Pacific Ocean Islands. *Conservation Biology* 24: 541-552.

Benzoni, F., and M. Pichon
2007. Taxonomic re-appraisal of zooxanthellate Scleractinian Corals in the Maldive Archipelago. *Zootaxa* 1441: 21-33

Gardiner, J.S.
1903. *The Fauna and Geography of the Maldives and Laccadives Archipelagoes*. Cambridge University Press, London and New York.

Gaines, S.D, C. White, M.H. Carr, and S.R. Palumbi
2010. Designing marine reserve networks for both conservation and fisheries management. *Proc. National Academy Sciences*. 107 (43): 18286-18293

Hamel, M., and S. Andréfouët
2012. Biodiversity-based propositions of conservation areas in Baa Atoll, Republic of Maldives. *Atoll Research Bulletin* 590: 223-235

Chabanet, P., P. Durville, R. Fricke, H. Amir, and L. Vigliola
2012. Checklist of the coral reef fishes of Baa Atoll, Maldives. *Atoll Research Bulletin* 590: 143-161

Criquet, G., L. Vigliola, and P. Chabanet
2012. Spatial variation in otolith chemistry of *Epinephilus merra* in Baa Atoll, Maldives. *Atoll Research Bulletin* 590: 203-208

Gravier-Bonnet N., and C. Bourmaud

2012. Hydroids (Cnidaria, Hydrozoa) of Baa Atoll (Indian Ocean, Maldives Archipelago). *Atoll Research Bulletin* 590: 85-123

Kench, P.S.

2012. The geomorphology of Baa (South Maahosmadulu) Atoll and its reef islands. *Atoll Research Bulletin* 590: 1-29

Kench, P.S.

2011. Maldives. In Hopley D. (Ed.) *Encyclopedia of Modern Coral Reefs: Structure Form and Process.* Springer, The Netherlands, p. 648-653.

Lasagna, R., G. Albertelli, P. Colantoni, C. Morri, and C.N. Bianchi

2010. Ecological stages of Maldivian reefs after the coral mass mortality of 1998. *Facies* 56 : 1-11.

McClanahan, T.R.

2000. Bleaching damage and recovery potential of Maldivian coral reefs. *Marine Pollution Bulletin* 40 - 7: 587-597.

Payri, C., A. D.R. N'Yeurt, and L. Mattio

2012. Benthic algal and seagrass communities in Baa atoll, Maldives. *Atoll Research Bulletin* 590: 31-66

Sattar, S., S. Andréfouët, M. Ahsan, S. Adam, C. Anderson and L. Scott

2012. Status of the coral reef fishery in an atoll country under tourism development: the case of Central Maldives. *Atoll Research Bulletin* 590: 163-186

Sattar, S., H. Amir, and S. Adam

2012. Reef fish tagging programme – Baa Atoll pilot project. *Atoll Research Bulletin* 590: 187-200

Stoddart, D.R. (Ed.)

1966. Reef studies at Addu atoll, Maldive Islands. Preliminary results of an expedition to Addu atoll in 1964. *Atoll Research Bulletin*, 116: 1-122.

Wallace, C.C., and H. Zahir

2007. The 'Xarifa' expedition and the atolls of the Maldives 50 years on. *Coral Reefs*, 26, 3-5.

Zahir, H., W. Allison, G. Dews, J. Gunn, A. Rajasurya, J. Tamelander, J.L. Solant JL, H. Sweatman, A. Thompson, and M. Wakeford

2006. Post-tsunami status of the coral reefs of the silands and atolls of the Maldives. In: Wilkinson CR, Souter D, Goldberg J (eds) *Status of coral reefs in tsunami affected countries: 2005.* Australian Institute of Marine Science, Townsville, pp 111–120.

THE GEOMORPHOLOGY OF BAA (SOUTH MAALHOSMADULU) ATOLL AND ITS REEF ISLANDS

BY

PAUL S. KENCH

ABSTRACT

Historically there have been few detailed geomorphic studies of the reefs and reef islands of the Maldives archipelago. The earliest studies were largely descriptive and latter studies sparse and ad hoc. Over the past decade there has been a focussed research effort in Baa Atoll (also known as South Maalhosmadulu Atoll) aimed at improving understanding of the geomorphic characteristics, morphodynamics, evolution and process controls on island formation and change. This paper synthesises this research and considers the broader significance for islands in the Maldives.

INTRODUCTION

Until recently there have been few detailed studies of the geomorphology of reefs and reef islands in the Maldives archipelago. Earliest scientific investigations of the Maldives involved hydrographic observations of the archipelago by Commander James Moresby 1835–1838. This work produced detailed hydrographic charts of the reef system, which remain the most accurate records of bathymetry in the archipelago. The turn of the twentieth century saw the first expeditions to the Maldives to document the taxonomy and biogeography of reef biota and make observations of oceanographic conditions. Most notable were the expeditions of James Stanley Gardiner (1899–1900) who undertook the first descriptions of marine and terrestrial fauna and flora as well as observations of reef structure (Gardiner, 1903) and Alexander Agassiz (in 1901–1902) who undertook sampling and description of biological aspects of the reefs (Agassiz, 1903). Of note, Gardiner also made observations of some islands and reefal deposits including a selection from the reefs of southern Baa Atoll.

Between 1933 and 1934 Seymour Sewell led the "John Murray" expedition to the Maldives in which he undertook detailed geomorphic observations of a number of atolls and islands (Sewell, 1936a, b). The "Xarifa" expedition (1957-1958) undertook investigations of the sub-littoral ecology and structure of reefs in many atolls in the archipelago (Hass, 1965). This expedition was notable for its taxonomic investigation of faunal and floral communities, identification of high species diversity, and establishment of baseline monitoring locations for future reference of reef community dynamics (Wallace and Zahir, 2007). A British expedition also studied the marine and terrestrial geomorphology and ecology of Addu Atoll (Stoddart, 1966).

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Based on these early observations Gardiner and Sewell speculated as to the origin, formation and process controls on island distribution (Gardiner, 1903; Sewell, 1936b). For example, cemented rocks in the island of Maamaduvvari (Baa Atoll) were interpreted by Gardiner as evidence of a higher sea level. Furthermore, Sewell (1936b) undertook detailed observations of islands in Goidhoo Atoll and surmised that island distribution was related to exposure to the oceanic swell regime with islands absent along high energy windward margins of atolls.

Since these early expeditions the research effort in the Maldives has been limited and narrowly focused on specific aspects of reef ecology, geology, and management. As a result, large gaps exist in scientific knowledge and many atolls have not been visited by scientists since Gardiner and Sewell. However, over the past decade there has been a concerted effort to investigate aspects of reef and island geomorphology in Baa Atoll. This paper summarises this work and examines the geomorphological characteristics of Baa Atoll and its reef islands. The focus of the paper is on the Holocene development of the atoll and its islands based on a synthesis of recent field investigations. Results are discussed in light of future trajectories of reef islands in Baa Atoll.

GEOLOGICAL SETTING

The Maldives archipelago comprises a chain of coral reefs and reef islands situated 700 km southwest of Sri Lanka (Fig. 1). The archipelago extends 868 km from Ihavandhippolhu in the north (6°57' N) to Addu Atoll (0°34' S) just south of the equator. Comprising 2,041 reefs (Naseer and Hatcher, 2004) the archipelago is globally unique in biological diversity, the range reef structures it possesses and their mode of evolution.

The archipelago constitutes the central section of the Laccadives – Maldives – Chagos submarine ridge, which in turn is part of a larger feature that stretches from the early Tertiary Deccan Traps of India to the volcanically active zone of Reunion. The Deccan Traps were the first manifestation of the stationary mantle hotspot that subsequently produced the volcanic ridge underlying the Maldives. Northward drift of the Indian Plate and northeastward motion of the African plate has resulted in northward age progression along this ridge (Duncan and Pyle, 1988; Duncan and Hargreaves 1990; Tiwari et al., 2007).

The history of formation of the Maldivian atoll systems differs to the subsidence model proposed by Darwin (1842). The basement rocks underlying the Maldives are Eocene volcanics (55 million years old). These basement volcanics are capped by up to 3,000 m of limestones. Carbonate accumulation through the Tertiary was controlled by phases of aggradation and progradation modulated by large oscillations in sea level (Aubert and Droxler, 1992; Purdy and Bertram, 1993; Belopolsky and Droxler, 2003; Kench, 2011). During the Quaternary the dominant mode of reef development has been vertical coral reef growth. This vertical reef growth is a consequence of high-amplitude sea-level fluctuations during the Pliocene-Pleistocene, producing alternate periods of exposure and submergence. During periods of submergence reefs accreted vertically to fill the accommodation space. The Holocene is the most recent of these reef growth phases.

Climatic Controls

The physical characteristics of atolls and reefs of the Maldives show marked latitudinal variations. Northern atolls are characterized by a heavily dissected atoll reef rim, numerous lagoonal patch reefs and faros and moderate lagoon depths (40-50 m).

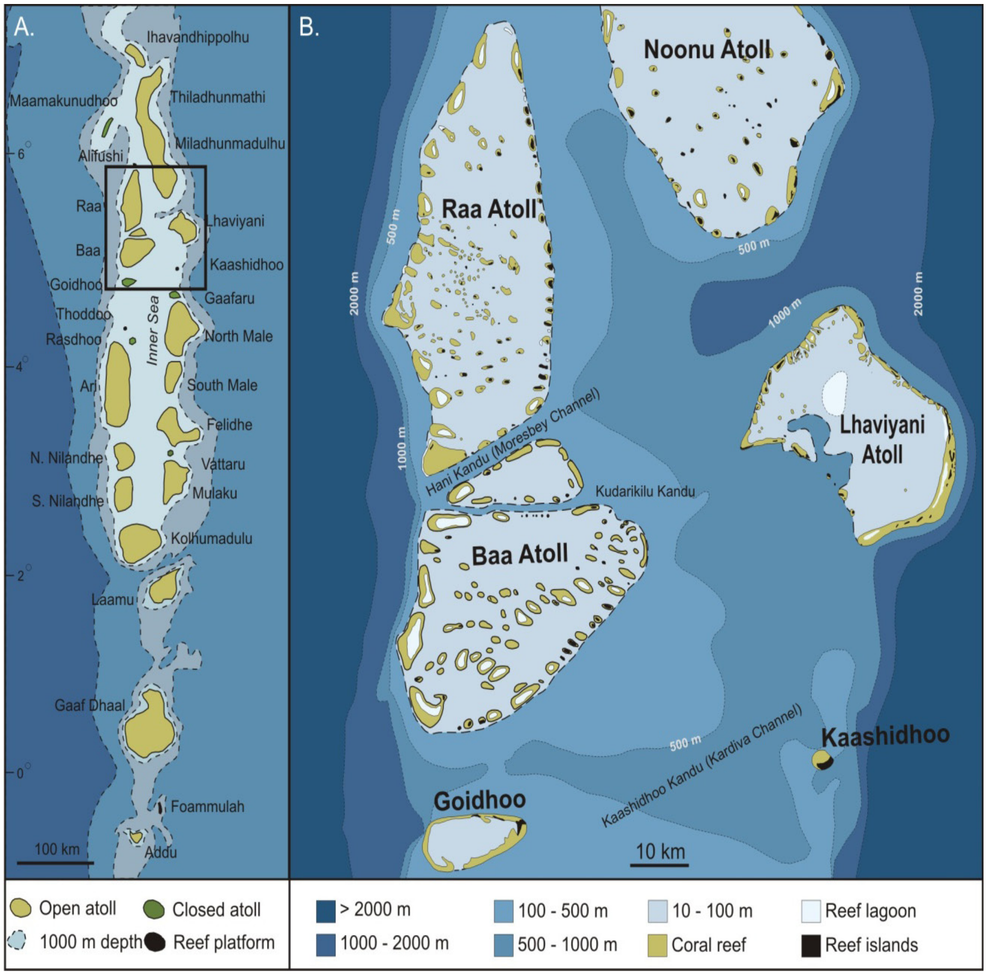

Figure 1. Field setting of the Maldives archipelago and Baa atoll (A). Regional setting of Baa and neighbouring atolls (B).

Reef islands are located on the peripheral and lagoonal patch reefs of these northern atolls. In contrast, southern atolls are characterized by more continuous atoll reef rims, higher proportion of peripheral reef rim containing islands, few lagoonal patch reefs and deeper lagoons (70-80 m, Woodroffe, 1993).

Longitudinal variations in morphology have been attributed to broad north-south gradients in climate and oceanographic conditions. The archipelago is subject to monsoonal conditions that switch from the west to northeast in a predictable fashion. The intensity of oscillating monsoon conditions increases to the north. Incident wave energy and rainfall both reduce in magnitude and intensity toward the north. Spatial gradients in boundary controls can influence rates of solutional lowering of lagoons during glacial and sediment transport and island formation processes on reef platforms. periods, and during highstands can control contemporary coral reef growth, sediment production

PHYSIOGRAPHIC CHARACTERISTICS OF BAA ATOLL

Baa Atoll is located in the Northern Province and western side of the double chain of atolls that comprise the Maldives archipelago (Fig. 1). Baa is surrounded by a number of other atolls: Raa Atoll to the north, separated by the narrow Moresby Channel; Noonu and Lhaviyani Atolls to the northeast and east, on the eastern side of the inner sea; and, the enclosed Goidhoo Atoll located approximately 20 km to the south (Fig. 1B). Collectively these neighbouring atolls afford a measure of protection to oceanic swell energy impacting Baa Atoll from the north to eastern sectors. To the southeast and also located on the eastern margin of the inner sea is the small reef platform island Kaashidhoo. However, the small size of this platform and distance from Baa suggest its influence on energy exposure is limited. Baa is exposed to ocean swell along its western and southwest margins.

The western reefs of Baa Atoll grade steeply to depths in excess of 1000 m. In contrast, on the eastern boundary the bathymetry of the shallow inner sea grades more gently to 500 m (Fig. 1B). Channels separating Baa Atoll from Raa in the north and Goidhoo in the south reach depths of 240 m and 560 m respectively.

At the gross scale the structure of Baa Atoll can be divided into two sections; a large triangular-shaped rim of reef platforms in the south and a smaller triangular rim of reefs in the north separated by the narrow Kudarikilu Kandu (channel; Fig. 2). A network of individual reef platforms that extend 122 km and enclose a lagoon of 1,127 km^2 defines the atoll periphery. The atoll is 38 km wide (on its longest west-east axis) and 46 km long along the southwest to northeast axis.

Baa Atoll contains 105 individual reef platforms with a total reef area of 263 km^2. The size and location of the reef platforms varies markedly within the atoll. Forty-nine reefs occur on the atoll margin. The western rim of Baa comprises six large platforms that have a maximum length of 8.2 km and 4.2 km width. Most of these western reefs have internal lagoons. The remainder of the atoll periphery is characterised by smaller reef platforms typically less than 1 km in maximum length and 0.5 km in width (Fig. 2). There are 56 lagoon reefs, most of which are clustered in the southern and central sector of the lagoon. A number of lagoonal reefs also straddle either side of the Kudarikilu Channel in the north. Eleven of the lagoon reefs are faro.

There are a total of 33 major passages that connect the open ocean and lagoon around atoll rim. These passages range in width up to 4.2 km with a total passage length of 44.5 km. Consequently, the atoll structure can be categorised as ‘open’, with an effective aperture of 0.37. The bathymetry of Baa Atoll is characterised by passages that in general are 35-56 m in depth. One exception is the narrow Kudarikilu channel where depths reach 256 m. The depth of the majority of the lagoon ranges from 30–50 m. However, there is a slightly deeper sector that ranges from 50 m to 60 m located in southwestern and central section of the lagoon (Fig. 2).

There are 61 vegetated islands and at least four unvegetated sand cays located on the reef platforms of Baa Atoll. The spatial distribution, geomorphological and sedimentological characteristics of these islands are described in detail in this study.

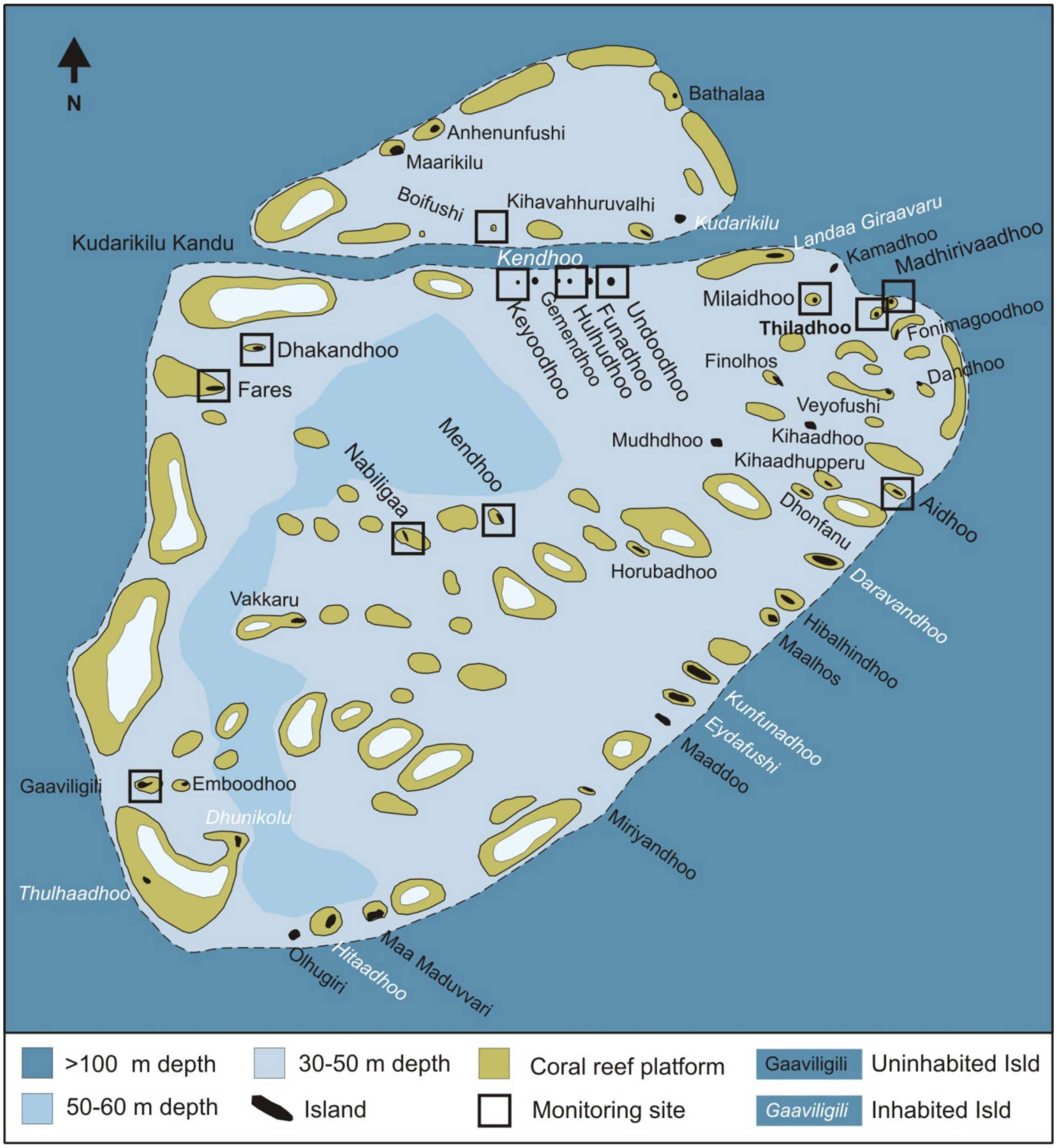

Figure 2. Baa Atoll detailing the distribution of reefs and reef islands.

Oceanographic Regime

The climate of the Maldives can be divided into two monsoon periods marked by strong reversals in wind direction that are confined to a narrow range of wind angles. Summary wind data since 1964 (Fig. 3A, B) indicate that the Maldives experience southwest to northwest winds (~ 225–315°) from April to November (westerly monsoon) with a mean wind speed of 5.0 ms^{-1}. In contrast, winds from the northeast-east (~ 45-90°) prevail from November to March (northeast monsoon) with a mean wind speed of 4.8 ms^{-1} (Fig. 3A, B). Wind strength is most variable during the cross-over between northeast and westerly monsoons with mean wind speed falling to 3.5 ms^{-1} in March (Department of Meteorology, 1995).

Information on the deepwater wave climate is limited, but satellite altimetry wave climate data (for a ten-year period) for the region (Young 1999) indicates the dominant swell approaches from southerly directions (Fig. 3D). On a seasonal basis, swell is from the south-southwest from April to November with a peak significant wave height (H_s) of 1.8 m in June, and from the south to southeast directions from November to March with a minimum H_s of 0.75 m in March (Fig. 3C, D).

The broadscale oceanography of the atolls of the Maldives has been poorly studied. Atoll-specific circulation and current patterns are controlled by the interaction of tide and wave processes with atoll structure. As noted above, the heavily dissected character of the Baa Atoll rim indicates the effective aperture of the atoll (proportion of gaps in the reef) is 37%. Consequently, the atoll is considered to be 'open' and allows penetration of tides and waves into the lagoon. The atoll is influenced by a microtidal regime with a spring tide range of approximately1.2 m.

At the atoll scale Kench et al. (2006) examined wave processes across Baa Atoll. They showed that wave energy affecting the atoll varies between monsoon seasons and is spatially variable within the atoll in each monsoon. Wave energy impacting the atoll is considerably greater during the westerly monsoon. Furthermore, atoll structure promotes significant changes in wave energy and wave characteristics across the atoll. Short period (3-8 s) monsoon-driven wave energy, which is significant on windward reefs, is dissipated on the peripheral reef network and the density of lagoonal patch reefs limits development of locally generated wind wave energy across the lagoon. However, longer period swell (8-20 s) propagates through the lagoon to leeward reefs. A windward to leeward decay in wave energy was evident in the westerly monsoon, but not in the northeast monsoon, when long period swell (from the southwest) remains significant on western reefs. Net energy calculations that account for seasonal changes in wave energy across the atoll identify a steep west-east gradient. In general, western reefs are dominated by westerly flowing energy that is 4.5-7 times the total energy input elsewhere in the atoll. Wave energy on central reefs is balanced whereas net energy on eastern reef platforms is dominated by eastward propagating energy. This steep energy gradient is likely to have geomorphic significance for reef growth and reef island development change throughout the atoll. As shown by Kench et al. (2006), for each individual reef platform incident wave energy is controlled by the relative presence or absence of boundary oceanic swell, the monsoonally forced wind-waves generated external and internal to the lagoon, as well as local sheltering factors promoted by proximity to other reefs.

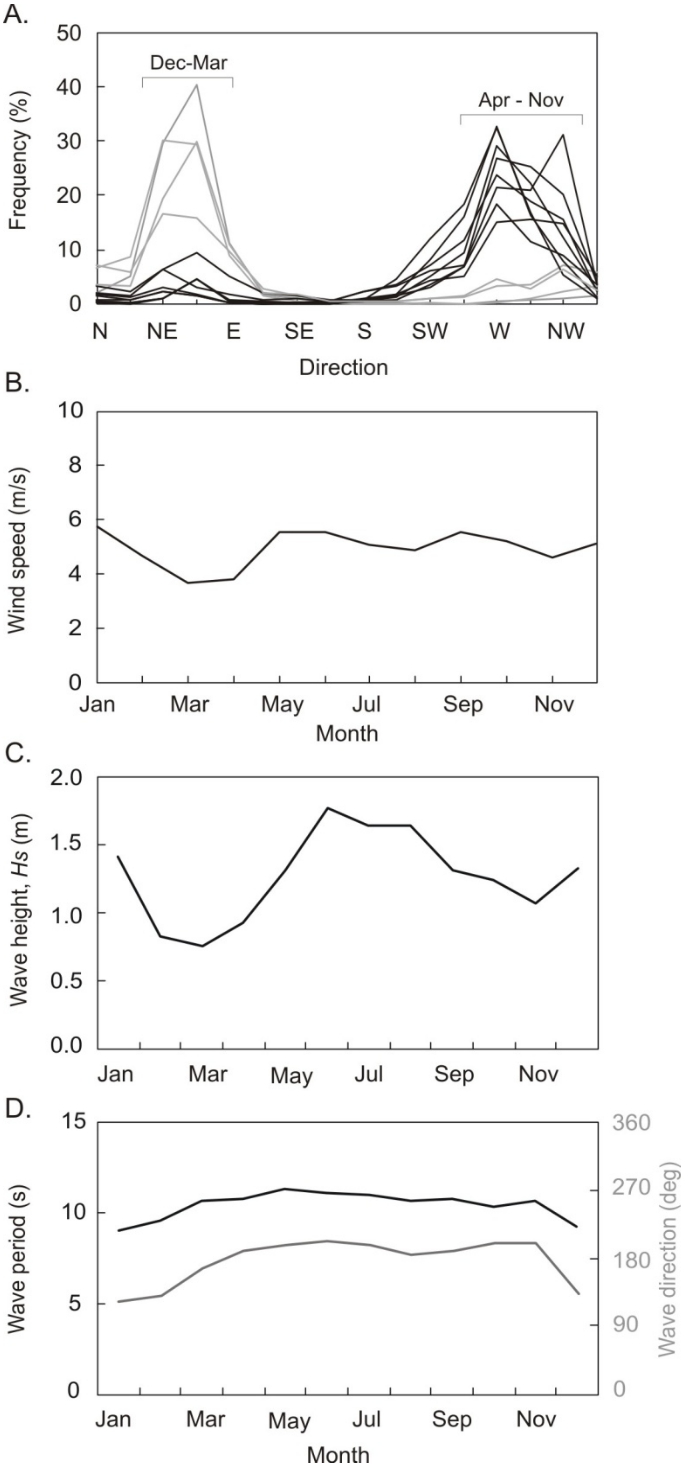

Figure 3. Summary of Maldives wind and wave climate over a 10 year period. A) Percent frequency monthly wind direction. B) Mean wind speed. C) Significant wave height in region of Baa Atoll. D) Wave period and direction in region of Baa Atoll.

HOLOCENE REEF DEVELOPMENT

The contemporary surface morphology of the Maldivian reefs is the result of coral reef growth on Pleistocene foundations over the past 10,000 years. The Holocene reef growth history of the Maldives has only recently been resolved in detail based on drill cores from Ari and Baa Atolls (Gischler, 2008; Kench et al., 2009a). Of relevance to this discussion are three closely spaced rotary drill cores extracted from the Hulhudhoo reef flat in the central section of Baa Atoll lagoon. A summary of the drill cores from Hulhudhoo is presented in Figure 4 and radiometric dates on 23 coral samples from the cores are summarised in Table 1. The data provide insights into the Holocene development or reefs in Baa Atoll.

Reef Cores

The outer reef flat core penetrated 14.6 m through the outer reef surface and terminated in highly porous reef rock with recrystallisation and discoloration, characteristic of Last Interglacial reef limestone (Montaggioni, 2005; Woodroffe, 2005). Overlying this basal rock the core comprised alternating massive corals (predominantly poritids and faviids) and coral rubble (with encrusting coralline algae and little sand matrix).

The central and inner reef flat cores penetrated 6.2 m and 7.2 m below the reef surface respectively, terminating in *Halimeda*-rich sand (Fig. 4). Above these basal sediments the cores comprised alternating layers of massive corals (*poritids, acroporids* and *faviids*), coral rubble and sand (Fig. 4A).A fourth core was extracted through the island ridge using a combination of hand auger and drill techniques (Kench et al., 2005). The island ridge core penetrated unconsolidated, medium-grained island sands in the upper 1.6 m before encountering multiple layers of cemented sand (beach rock or cay sandstone). Underlying the island sediments in situ coral and reefal sediments were encountered.

Kench et al. (2009a) noted a number of conspicuous features of the massive corals in cores. First, favid and acroporid species dominate below a depth of 5 m. Second, poritid corals dominate the core above 5 m as well as on the contemporary reef flat. Third, the growth structure and orientation of corallites within the massive corals are indicative of in situ growth position and the thickness of the fossil corals in cores (typically 0.2 to 0.4 m) was comparable to that of living microatolls on reef flats surrounding the study islands.

Radiometric Ages of Core Material and Reef Growth

Uranium-series dating of the basal reef sample in core 1 yielded a minimum age of 122,000 ± 7.0 ka (at -14.12 below msl) confirming this limestone as Last Interglacial reef. Results of dating coral material above the interglacial surface provide the timing of reef establishment and chronology of reef growth in the Holocene. An age of ca 8,100 cal yBP (Table 1), immediately overlying the Last Interglacial surface records the initiation of the Holocene reef growth on Hulhudhoo. This age for Holocene reef initiation is comparable to that from Rasdhoo Atoll (Gischler et al., 2008) and other oceanic reefs in the western Indian Ocean (Montaggioni, 2005). Further dates indicate steady vertical reef growth followed from ca 8,100 to 6,400 cal yBP (to a water depth of -2.17 m below msl)

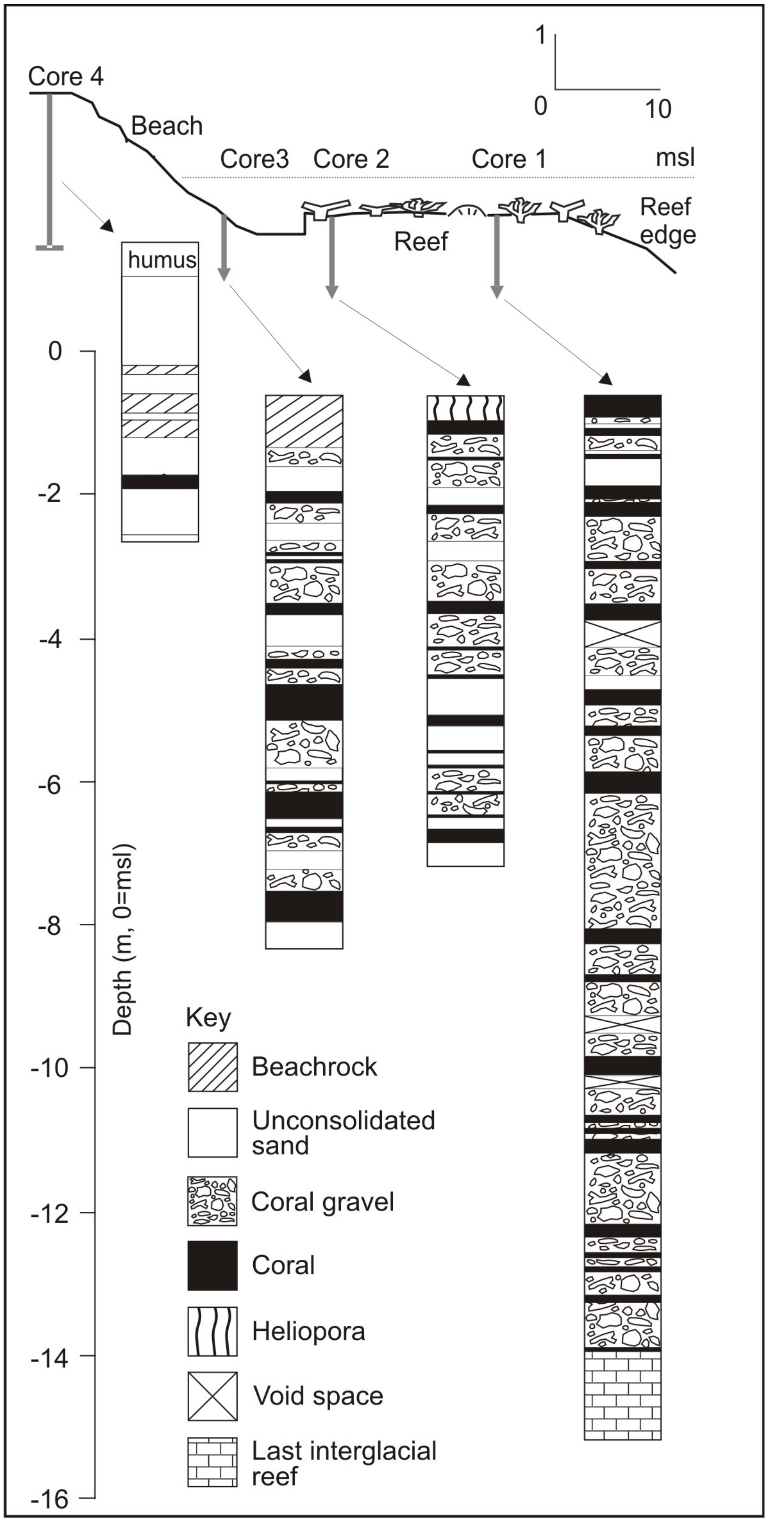

Figure 4. Reef drill cores on southern Hulhudhoo reef flat, Baa Atoll, Maldives. Topography of island margin and reef flat shown at top. After Kench et al., 2009a.

Table 1. Radiometric ages from reef cores and microatolls on Hulhudhoo and Funadhoo Islands, Baa atoll.

Lab code	Island and sample location	Sample material	Depth relative to MSL(m)	Conventional age (yr B.P.)	Calibrated age range (95.4% probability)(cal. yr B.P.)
20801	HUL C1	*Favid sp.*	-13.89	7,802 ± 53	8,302 - 7,970
20802	HUL C1	*Favid sp.*	-13.17	7,758 ± 51	8,258 - 7,935
20803	HUL C1	*Favid sp.*	-12.17	7,732 ± 50	8,227 - 7,914
20804	HUL C1	*Favid sp.*	-11.07	7,465 ± 50	7,940 - 7,646
20805	HUL C1	*Favid sp.*	-8.07	7,053 ± 48	7,558 - 7290
20806	HUL C1	*Favid sp.*	-6.07	6,864 ± 48	7,413 - 7,119
20807	HUL C1	*Favid sp.*	-5.27	6,846 ± 48	7,404 - 7,083
20808	HUL C1	*Porites sp.*	-4.77	6,566 ± 47	7,128 - 6,742
20809	HUL C1	*Favid sp.*	-3.72	6,292 ± 46	6,759 - 6,419
20810	HUL C1	*Porites sp.*	-2.17	6,144 ± 46	6,599 - 6,280
20811	HUL C1	*Porites sp.*	-1.17	4,872 ± 46	5,226 - 4,826
20812	HUL C1	*Porites sp.*	-0.87	4,548 ± 52	4,798 - 4,401
20818	HUL C2	*Acropora sp.*	-6.87	6,882 ± 47	7,415 - 7,145
20819	HUL C2	*Acropora sp.*	-6.17	6,840 ± 57	7,406 - 7,056
20820	HUL C2	*Pocillopora sp.*	-5.12	6,551 ± 47	7,113 - 6,723
20821	HUL C2	*Porites sp.*	-4.17	6,614 ± 61	7,177 - 6,768
11302	HUL C2	*Porites sp.*	-2.50	5,802 ± 60	6,210 – 5,910
20813	HUL C3	*Favid sp.*	-7.87	7,078 ± 48	7,571 - 7,310
20814	HUL C3	*Favid sp.*	-6.72	7,052 ± 48	7,557 - 7,290
20815	HUL C3	*Porites sp.*	-5.17	6,769 ± 57	7,322 - 6,954
20816	HUL C3	*Porites sp.*	-2.87	6,041 ± 46	6,474 - 6,182
20817	HUL C3	*Porites sp.*	-1.36	4,404 ± 42	4,567 - 4,168
11302	HUL C4	Reef rock	-1.17	4,078 ± 70	4,140 – 3,720
12663	HUL RF	*Porites* FMA	-0.25	3,679 ± 45	3,550 – 3,340
20797	FUN RF	*Porites* FMA	-0.06	2,566 ± 39	2,278 - 1,911
20798	FUN RF	*Porites* FMA	-0.06	2,578 ± 45	2,289 - 1,919

Note: Radiocarbon dates obtained from the Radiocarbon Dating Laboratory, University of Waikato, New Zealand. Ages calibrated by using OxCal version 3.5 (Bronk Ramsey, 2001) with the marine data set (Stuiver et al., 1998) and Delta-R value of 132 ± 25 as best estimate for the central Indian Ocean reservoir effect (Southon et al., 2002). FMA = fossil microatoll, HUL = Hulhudhoo, FUN = Funadhoo. From Kench et al. 2009a.

at a mean rate of ~7 mm/y. The rate of vertical reef accretion then slowed to ~ 0.8 mm/y ca 6,400 cal yBP, the reef first reaching near its present level approximately 4,000-4,500 yr ago. Ages of the uppermost poritids from cores 1 and 2 and of *in situ* fossil *Heliopora* in core 4 have an age range from ca 3,900 to 4,600 cal yBP suggesting the Hulhudhoo reef reached its maximum width at this time.

Comparison of the age and elevation of dated corals between cores indicates that: reef development was dominated by vertical growth from ca 8,000 to 6,500 cal yBP with no evidence of lateral extension of the fore reef to seaward. Subsequently, the outer section of reef accreted at a faster rate than the inner reef between ca 6,500 and 4,500 yr ago (Table 1).

Emergent Reef Flat Corals

In addition to reef cores a number of radiometric dates were obtained from emergent fossil microatolls on Hulhudhoo and the neighbouring island Funadhoo (Fig. 2, 5). On Hulhudhoo, a sample from one *Porites* microatoll dated at ca 3,400 cal yBP is situated 0.25 ± 0.07 m below msl, which is 0.18 ± 0.05 m above the upper limit of present living microatolls. Samples from two *Porites* microatolls dated at ca 2,100 cal yBP from Funadhoo were up to 0.37 ± 0.06 m above the upper limit of contemporary coral growth (0.06 m ± 0.06 m below msl; Table 1). These microatolls outcrop at the island shoreline and overlie *in situ* fossil *Heliopora* (Fig. 5).

Seasonal movements of beach sands and coral rubble have abraded the upper surfaces of these fossil microatolls (Fig. 5). Thus the surveyed elevations represent minimum palaeo-sea level positions. Observations of the mean thickness of living microatolls throughout the atoll suggest that as much as 0.15-0.2 m has been removed by abrasion. It is conservatively estimated that coral growth occurred to at least 0.5 ± 0.1 m above present around 2,100 yBP. The presence of emergent fossil microatolls has profound implications for understanding sea level change.

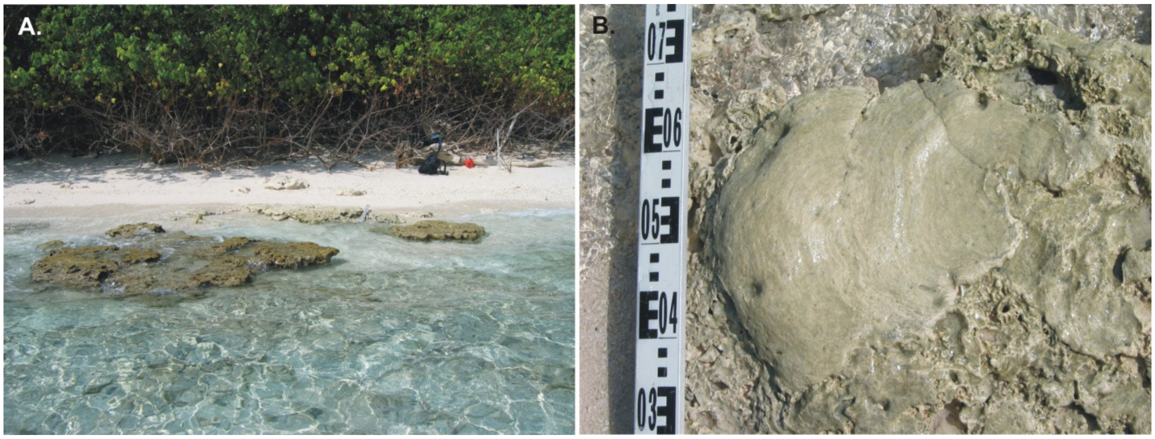

Figure 5. Photograph of *Heliopora* reef capped by fossil microatolls outcropping on eastern shoreline of Funadhoo (A). Photograph taken two hours prior to high tide. B) Abraded fossil microatoll in growth position above fossil *Heliopora* surface.

Sea Level History

The presence of massive living poritid and faviid corals, including microatolls, on the contemporary reef flats of Baa Atoll, together with the frequent occurrence of their fossil equivalents throughout the Hulhudhoo cores is indicative of a comparable palaeo-reef setting, suggesting that accretion of the Hulhudhoo reef closely tracked rising sea level. The presence of emergent fossil in situ microatolls provides a higher resolution late-Holocene sea-level indicator as their upper growth surface is constrained by subaerial exposure during low tides (Smithers and Woodroffe, 2000).

Based on these interpretations the Holocene sea level history in Baa Atoll can be inferred. The sea level record is divided into four distinct phases (Fig. 6). Phase 1 is characterised by a steady sea-level rise of ~ 7 mm/y, which flooded the last interglacial

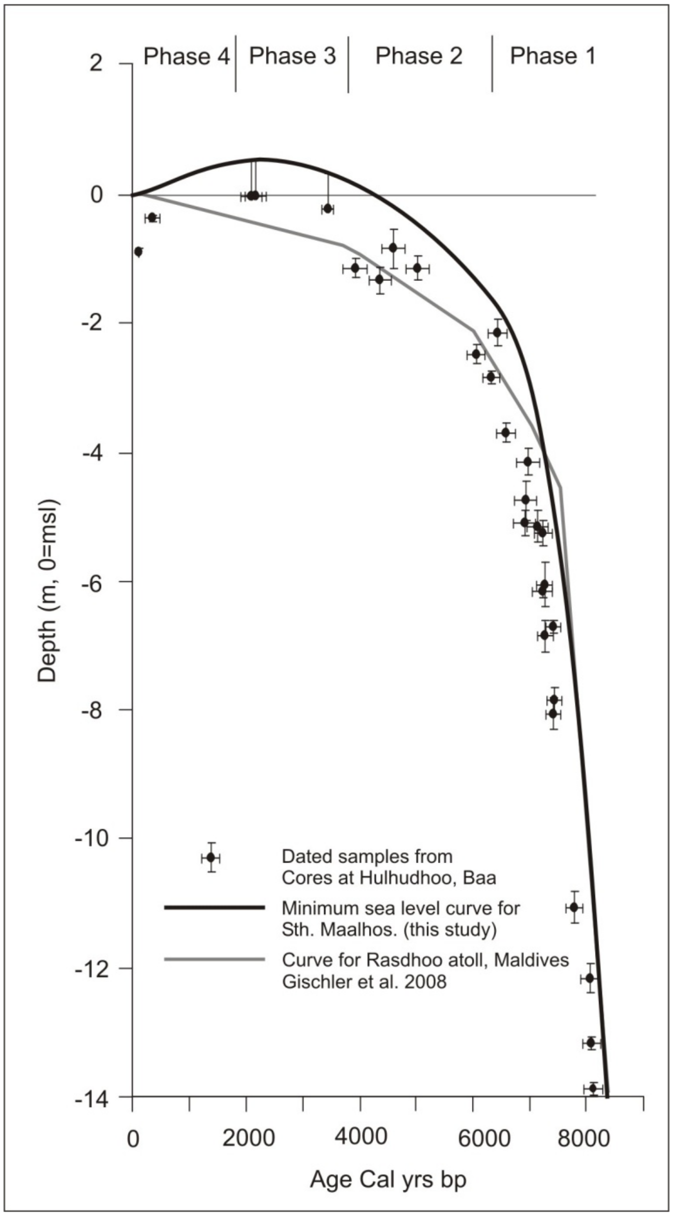

Figure 6. Age-depth plot of reef core and fossil microatoll samples. Inferred minimum sea level history represented by black line. Horizontal bars represent 2σ calibrated age range (Table 1) and vertical bars are defined by uncertainties of coral elevation. After Kench et al., 2009a.

surface around 8,100 to 6,500 cal yBP. Phase 2 spanned the period 6,500 to 4,500 cal yBP and is characterised by decrease in the rate of sea-level rise to <1 mm/y. Sea level first reached present level at around 4,500 cal yBP. During Phase 3 sea level continued to rise to at least 0.5± 0.1 m above present until ca 2,100 cal yBP. The fourth and final phase is the subsequent falling of sea level from the late-Holocene highstand to its current elevation.

These results clarify the pattern of Holocene sea level change in Baa Atoll which is of relevance to the entire Maldives archipelago. Of note, the mid-Holocene reef growth history is comparable to that described by Gischler et al. (2008) on Rasdhoo Atoll, although no evidence for a higher sea level was found at that location. The elevated microatolls on Baa provide unequivocal evidence of a late-Holocene sea level highstand ca 2,000-4,000 yr ago. At a regional scale these results are significant as they confirm that emergent reef build-ups are not missing from the central Indian Ocean as suggested by Camoin et al. (2004).

REEF ISLANDS OF BAA ATOLL

Baa Atoll contains 61 vegetated reef islands which are located on peripheral and lagoonal reef surfaces. In addition there are at least four unvegetated and ephemeral unvegetated sand cays. The vegetated islands and unvegetated sand cays in Baa are diverse in their morphological and sedimentary characteristics. As identified earlier physical descriptions of some of the islands in the southern part of the atoll were undertaken by Gardiner (1903) and provide a basis to examine island change.

Over the past decade there has been an increased research effort to better understand the geomorphic characteristics of islands in Baa Atoll, their evolution and morphodynamics (Ali, 2000; Kench and Brander, 2006; Kench et al., 2005; Kench et al., 2006; 2008). In particular, 13 islands throughout Baa Atoll were identified and established as the first sites of geomorphic monitoring in the Maldives (Fig. 2). These islands have been the focus of repetitive geomorphic surveys and mapping since 2002. Monitoring observations have been used to examine seasonal variations in island shorelines (Kench and Brander, 2006) and assess the impacts of the Indian Ocean tsunami on islands (Kench et al. 2006, 2007, 2008; Nichol and Kench 2008).

Physical Characteristics of Islands

The islands of Baa Atoll are found both on the peripheral reef rim (n=34) and internal lagoon reefs (n=31). A number of observations can be made with regard to the physical distribution of islands. First, there are only three islands located on the western exposed rim of the atoll and these are all small in size. Second, the highest density of islands occurs on the southern to eastern peripheral rim of the atoll. Third, exploration of descriptive characteristics between lagoonal and peripheral islands identified few meaningful differences. However, average island area is greater on peripheral islands (10.9 ha) compared to lagoonal islands (7.6 ha; Table 2).

Physical dimensions of islands are summarised in Table 3. Island size ranges from less than 1 hectare to more than 45 hectares. Over half of all islands (38) are less than 10 hectares in area and collectively account for 19% of total land area in the atoll. Islands between 10 and 30 hectares in area (23 in total) account for 67.5% of atoll land area. Of note, only two islands are larger than 30 hectares. Dharavandhoo is the largest island in the atoll at 45.5 ha in area. This elongate island is 1.32 km in length and 480 m in width. The second largest island Kunfunadhoo is 35 hectares in area. Collectively these two islands account for 13% of total land area in the atoll. Islands occupy varying proportions of their reef platforms ranging from less than 1% to a maximum of 71% on Olhugiri (x=23%). Islands are also found in a broad spectrum of planimetric shapes from linear to near circular. In general, island shape mirrors reef platform shape except where there are multiple islands on reefs or where the island is extremely small compared with reef area.

Table 2. Summary of vegetated island size classes in Baa atoll.

Island size	No. islands	Total island area (hectares)	Percent of total island area
< 1.0	6	2.1	0.35
1.0-9.99	30	110.3	18.6
10.0 – 19.99	15	211.2	35.6
20-29.99	8	189.3	31.9
30-39.99	1	35.0	5.9
>40	1	45.5	7.7

Geomorphic Characteristics of Islands

Surveys depicting the morphology of islands have been undertaken on 43 of the islands in Baa Atoll (Ali, 2000; Kench and Brander, 2006). Typical island cross-sections are presented in Figure 7 and can be divided into 3 characteristic morphologies. 1) Convex islands with simple convex ridges (Fig. 7A). Unvegetated sand cays or small vegetated islands which can experience washover under higher water level conditions typically exhibit this morphology. 2) Asymmetric islands with a high seaward ridge which slopes lagoonward. The island surface typically terminates in a more subdued ridge on the opposite side of the island (Fig. 7B). 3) Basin shape islands where high marginal ridges impound a lower elevation central depression (Fig. 7C). This is the most common island morphology and is typical of the medium to larger islands in the atoll.

There is significant variation in the elevation of island ridges. Ali (2000) reported a maximum ridge elevation on Funadhoo of 3.19 m above mean sea level (msl). Kench et al. (2008) show marked changes in ridge elevation both within islands and across the atoll that are related to energy exposure. In general, highest ridge elevations occur where shorelines are exposed to higher wave energy. Examining islands across a west to east transect Kench et al. (2008) found consistent variations in island ridge elevation within islands, with western exposed island ridges typically 0.5-1.2 m higher than leeward island ridges. Furthermore, they showed that the eastern island Thiladhoo had much lower elevation ridges (1.08 – 1.59 m) than western and central islands (1.44-2.51 m range). Kench et al. (2008) suggest the dominant westerly monsoon wave conditions are responsible for such spatial patterns with higher wave energy promoting greater swash excursion on island shorelines and greater run-up deposition.

Table 3. Physical characteristics of islands in Baa atoll.

Island name	Length (m)	Width (m)	Area (ha)	Ellipticity	Percent occu.	Location (P/I)
Nelivaru	55	20	0.1	0.36	0.1	P
Ahivahfushi	67	40	0.1	0.60	0.1	P
Kanufushee finolhu	80	25	0.1	0.31	0.1	P
Kanufushee G. Finolhu	80	30	0.1	0.38	0.1	P
Medhufinolhu	130	30	0.1	0.23	0.1	P
Nibiligaa	123	15	0.5	0.12	1.0	I
Ufuligili	250	30	0.5	0.12	0.2	P
Kudadhoo	130	60	0.6	0.46	0.1	P
Hanifaru	250	56	1.0	0.22	0.3	P
Gemendhoo	150	100	1.2	0.67	34.6	I
Boifushi *usc*	169	70	1.3	0.41	9.9	P
Maddoo-hulhudhoo	180	130	1.6	0.72	37.7	P
Keyodhoo	170	135	1.7	0.79	47.0	I
Bathalaa	138	132	1.8	0.96	0.8	P
Gaaviligili	330	150	1.9	0.45	2.1	P
Aidhoo	280	130	2.0	0.46	34.7	P
Dhandhoo	230	130	2.0	0.57	19.8	I
Hulhudhoo	224	200	2.2	0.89	44.3	I
Dhigufaru vinagadu	250	67	2.4	0.27	0.3	P
Bodufinolhu	750	60	2.5	0.08	0.1	P
Thiladhoo	230	200	2.7	0.87	18.7	I
Emboodhoo	300	100	2.8	0.33	21.8	I
Milaidhoo	250	200	3.0	0.80	10.3	I
Muthaafushi	630	75	3.0	0.12	4.3	I
Veyofushi	300	180	3.2	0.60	2.4	I
Voavah	289	49	3.2	0.17	3.0	I
Madhirivaadhoo	330	230	4.0	0.70	35.2	P
Hirundhoo	400	150	4.1	0.38	38.4	I
Kashidhoogiri	253	214	4.1	0.85	33.0	P
Kashidupper *usc*	358	25	4.3	0.07	0.8	I
Miriyandhoo	430	180	4.8	0.42	16.6	P
Dhakandhoo	400	230	4.8	0.58	46.7	I
Kanufushi	530	180	7.2	0.34	2.6	P
Funadhoo	430	350	7.8	0.81	44.7	I
Kihaadhunfaru	600	230	8.2	0.38	12.7	I
Udoodhoo	380	365	9.3	0.96	51.1	I
Fares	630	220	10.2	0.35	3.5	P
Mendhoo	530	280	10.5	0.53	25.8	I
Dhunikolhu	600	250	11.3	0.42	0.5	I
Vakkaru	750	250	11.8	0.33	4.8	I
Horubadhoo	750	230	12.0	0.31	51.3	I
Dhonfanu	680	220	12.6	0.32	26.4	I
Kihavahhuruvalhi	508	249	12.7	0.49	14.2	I
Kendhoo	600	350	13.7	0.58	61.6	I
Hibalhidhoo	830	300	14.3	0.36	21.4	P
Landaa-giraavaru	950	250	14.5	0.26	4.6	P
Mudhdhoo	675	350	16.0	0.52	47.4	I
Kamadhoo	530	460	16.8	0.87	50.8	P
Kudarikilu	521	391	16.8	0.75	38.1	P
Maaddoo	1380	350	18.8	0.25	51.5	P
Anhenunfushi	634	295	19.2	0.47	19.7	P
Olhugiri	550	400	20.0	0.73	71.0	P
Finolhos	900	300	20.5	0.33	46.0	I
Eydafushi	770	415	22.2	0.54	38.5	P
Maarikilu Kandu	708	426	22.2	0.60	42.2	P
Maalhos	750	490	23.2	0.65	54.6	P
Hithaadhoo	790	450	25.2	0.57	18.7	P
Kihaadhoo	800	490	26.4	0.61	65.0	I
Maamaduvvari	940	350	29.6	0.37	38.0	P
Kunfunadhoo	1420	360	35.0	0.25	42.1	P
Dharavandhoo	1320	480	45.5	0.36	48.9	P
Thulhaadhoo	380	230	5.0	0.61	0.2	P
Fonimagoodhoo	600	200	7.2	0.33	6.9	P

NB: Percent Occu. = percentage of reef platform occupied by island; P= peripheral reef, I=internal reef; usc = unvegetated sand cay

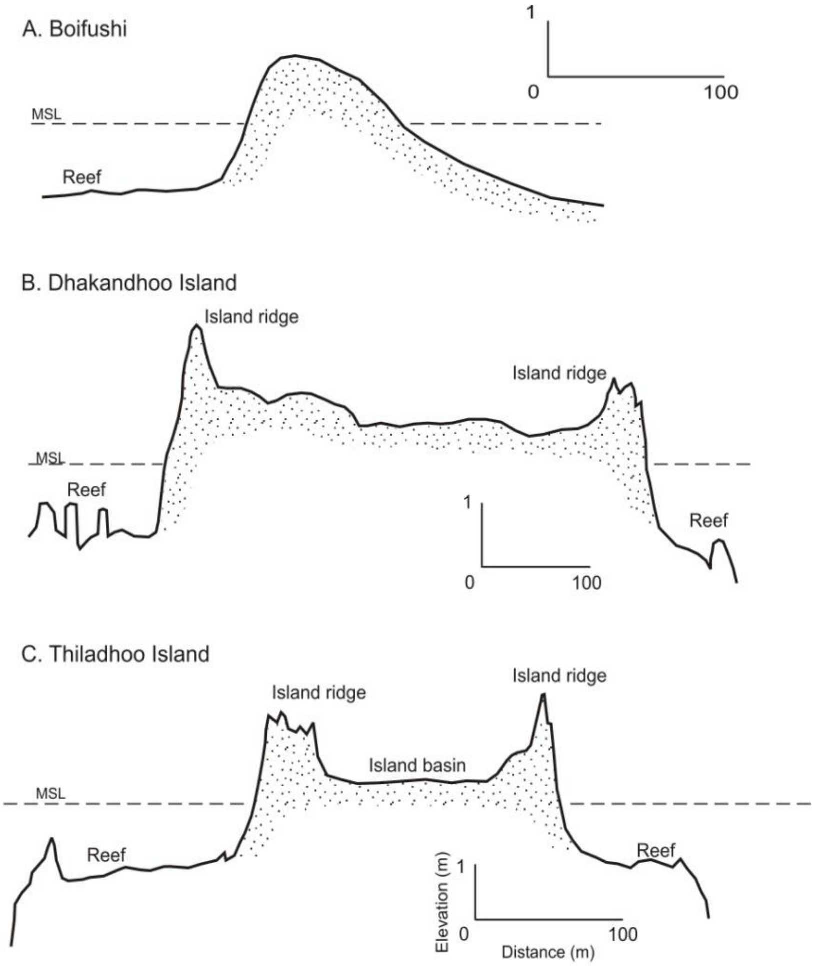

Figure 7. Characteristics morphologies of reef islands in Baa atoll. A) Convex morphology; B) Asymmetric ridge morphology; C) Basin morphology.

While island ridges are relatively high, the central island depression is substantially lower in elevation -typically less than 1.0 m above msl. While island morphologies can be reduced to three simple forms the surface morphology of islands exhibit complex morphologies at the island scale. For example, island surfaces can exhibit multiple ridge sequences. Furthermore, on some islands additional depressions exist that are occupied by mangrove (*faa*) or freshwater ponds (*kulhi*). At least three islands are known to have kulhi or faa (Dhakandhoo, Hirundhoo and Maamaduvvari). The presence of enclosed kulhi and faa signifies that small lagoons may have been closed through alongshore extension of island ridges during island development. Indeed, such a sequence of events has taken place on Maamaduvvari which was initially described by Gardiner (1903) as having a small lagoon but which has subsequently been occluded with the formation of a barrier across the northwestern section of the island.

Unconsolidated Island Sediments

The reef islands of Baa Atoll are composed entirely of calcareous sediments derived from the skeletal remains of reefal organisms. However, the texture, composition of sediments and degree of lithification of island sediments do differ between islands.

Gravel Deposits. On wave exposed sectors of the atoll periphery, islands are composed of coarse coral rubble. For example, on Ahivahfushi (northwest), Gaaviligili (southwest) and Aidhoo (northeast) the ocean shoreline consists of a sequence of gravel ridges that represent phases of island accumulation (Fig. 8A, B). Gravel deposits have also been identified on Ufulgili, Olhugiri and Maamaduvvari. The gravels are composed almost entirely of coral clasts. However, the lagoon ends of islands appear to be composed of sand-size material forming spits that extend lagoonward across the reef platforms.

Sand Deposits. The majority of leeward peripheral islands and all lagoon islands are composed of sand-size calcareous sediments (Fig. 8C, D). An analysis of more than 107 beach samples from 10 islands in Baa Atoll indicated that sediment size ranged from 0.7 to 2.0 phi (0.6 mm to 0.25 mm) although the mean size was approximately 1.4 phi (0.38 mm, Cameron, 2002). Ali (2000) reported a similar size range for island sediments of Baa Atoll. Sand islands consist of a vegetated island core, which is surrounded by an unvegetated and mobile beach.

The composition of 13 island sediment samples, from 9 islands, was examined by Ali (2000) (Table 4). Results indicate that sediment composition is dominated by coral (20-66%). *Halimeda* (up to 47%) and molluscan fragments are of secondary importance in deposits with foraminifera and other components comprising subordinate fractions (<10%). However, the number of samples analysed were too few to provide a robust assessment of the sediment composition or spatial differences in constituents contributing to islands. Such differences can occur within islands and are discussed later.

Table 4. Summary of the skeletal composition of 13 island samples from Baa Atoll.

Island	Depth (m)	Coral	Mollusc	Halim.	Foram	Alcyon.	Crust/Echin	Coralline algae	Unkn
Aidhoo	0.75	62.7	18.1	2.2	5.0	5.3	3.3	0.0	3.3
Aidhoo	1.20	40.7	25.0	11.6	7.5	6.4	5.4	0.0	3.4
Bodufinolhu	1.25	38.1	17.9	26.8	6.5	4.6	3.3	0.7	2.2
Fares	2.0	48.4	13.4	20.6	8.4	2.3	3.1	0.2	3.7
Hanifaru	0.98	52.2	7.9	21.7	7.6	1.8	5.3	0.7	2.8
M-Hulhudhoo	0.8	59.6	12.6	0.0	16.5	4.0	1.3	0.0	6.0
M-Hulhudhoo	Beach	53.6	23.6	1.4	5.2	7.2	3.5	0.6	4.9
Mendhoo	1.6	48.2	15.9	6.9	7.2	10.5	7.2	1.1	3.0
Nelivaru	2.95	44.7	17.5	17.3	11.9	0.8	3.6	0.4	3.8
Olhugiri	1.20	66.1	13.6	0.0	6.1	6.1	5.2	0.0	2.9
Olhugiri	1.8	42.8	23.6	18.3	9.5	1.3	2.2	0.7	1.6
Udoodhoo	1.15	20.6	8.3	47.4	9.3	7.5	3.0	0.0	4.0
Udoodhoo	Beach	55.8	12.5	1.3	10.3	8.8	4.7	3.5	3.1

Depth = depth below island surface; Halim. = *Halimeda*; Foram. = foraminifera; Alcyon. = Alcyonarian spicules; Crust/Echin. = Crustacean and Echinoids; Unkn. = unknown. Source (Ali, 2000).

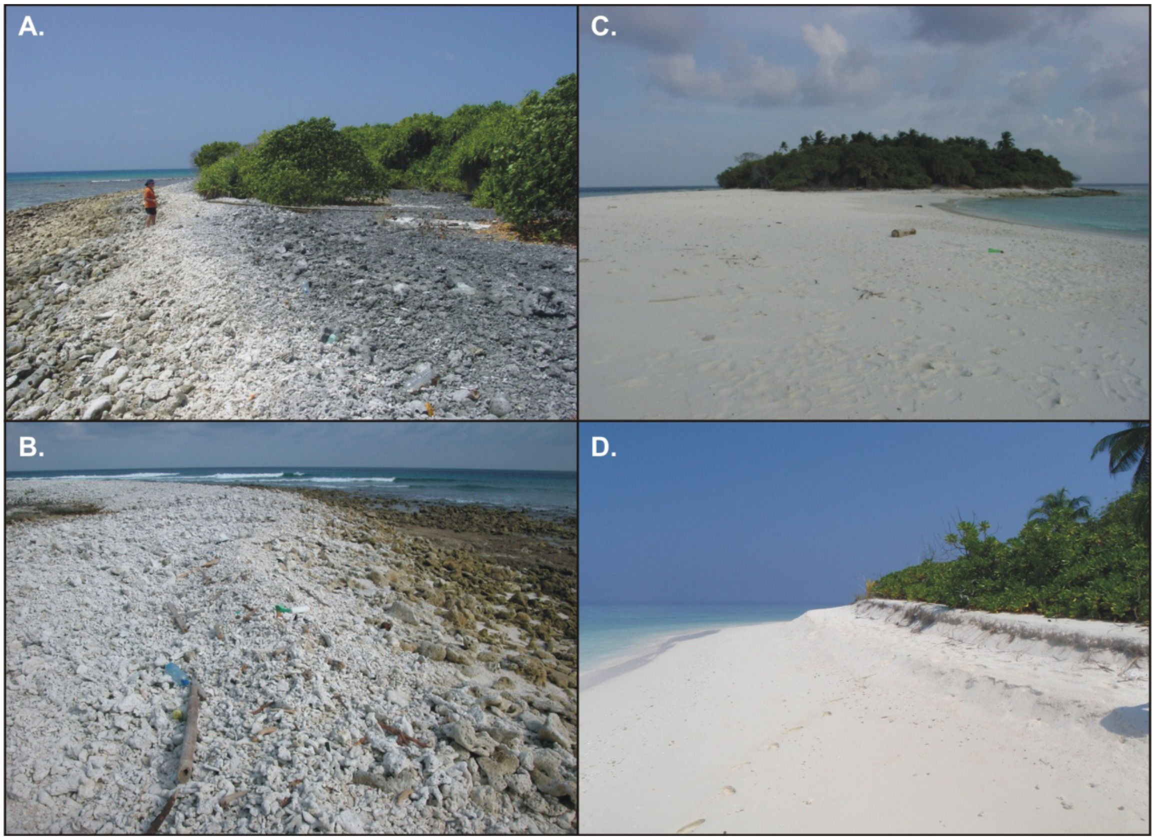

Figure 8. Examples of unconsolidated sedimentary materials comprising islands in Baa atoll. Gravel ridges on Gaaviligili (A) and Aidhoo (B); sand spit on Aidhoo (C) and typical beach on Milaidhoo (D) Location of islands shown in Figure 2.

Mobile Beaches. Beaches composed of sand-size material are very dynamic, with shorelines shifting position markedly at seasonal timescales. Seasonal monitoring of beach position using Global Positioning System (GPS) surveys was instigated on 13 islands in Baa Atoll in 2002 and provides a useful baseline to assess ongoing geomorphic changes in islands (Kench and Brander, 2006).Figure 9 shows summary GPS surveys documenting the position of beaches on selected islands between monsoon seasons. The data show large changes in beach position between monsoon periods. However, the net change in beach position was minimal on an annual basis (Kench and Brander, 2006). Furthermore, the degree of shoreline change appears to vary between islands of differing shape. For example, circular islands (e.g. Hulhudhoo) display larger changes in beach position around the island shoreline, whereas the elongate islands display more constrained shoreline change, principally around the apexes of islands. Based on detailed hydrodynamic investigations it has been established that observed beach change is driven by monsoonally-forced oscillations in wave and current processes (Kench et al., 2009b, c).

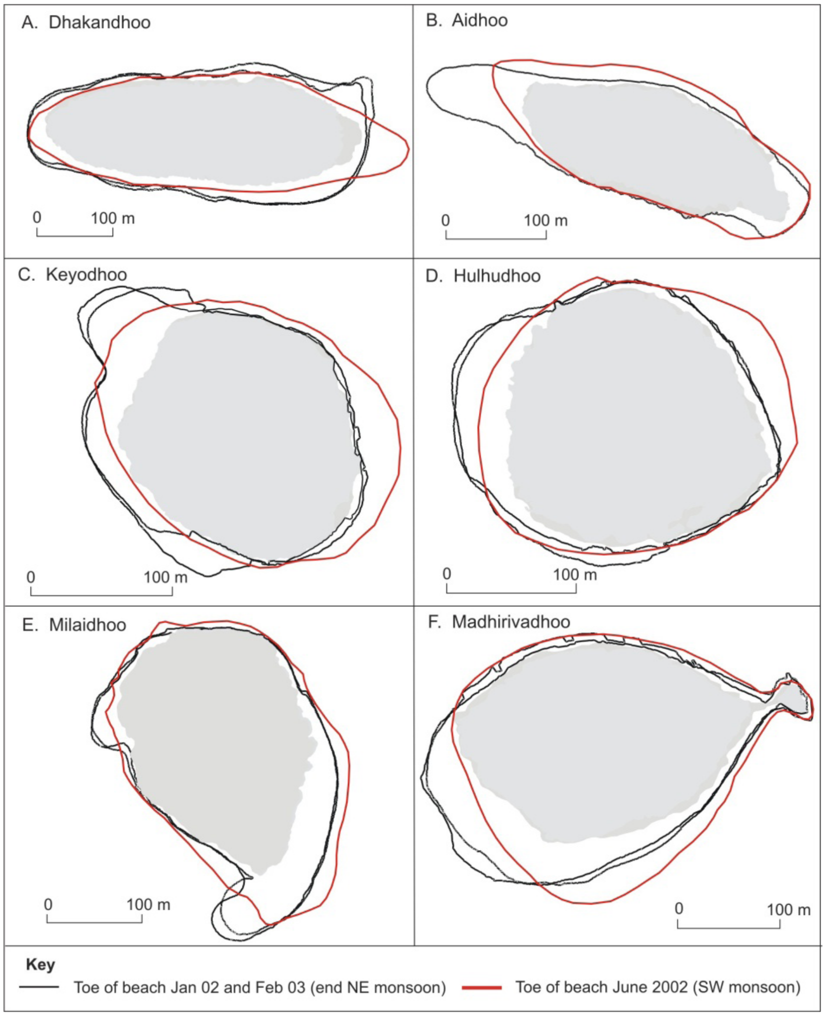

Figure 9. Seasonal beach change around selected islands in Baa Atoll. Selected islands are part of a monitoring network in the atoll. Location of islands shown in Figure 2.

Seasonal beach change is geomorphically important. It is responsible for large volumetric fluxes of sediment around island shorelines on a seasonal basis; it regulates the transfer of sediments between the reef and vegetated core of the island surface (Kench 2008), and it occupies the inner reef flat surface and prevents coral growth. Indeed the footprint of beach demarcates the boundary of the inner reef platform moat. Beyond the moat upward reef growth has continued until confined by sea level, with the living reef edge elevated up to 1.0 m above the moat surface.

Lithified Island Sediments

A range of lithified sediments are found on the islands of Baa Atoll (Fig. 10). They are found in distinct geomorphic zones, have different modes of formation and occupy different elevations with respect to sea level. The lithified sediments can in some cases be extensive and can assist in the stabilisation of islands and their shorelines.

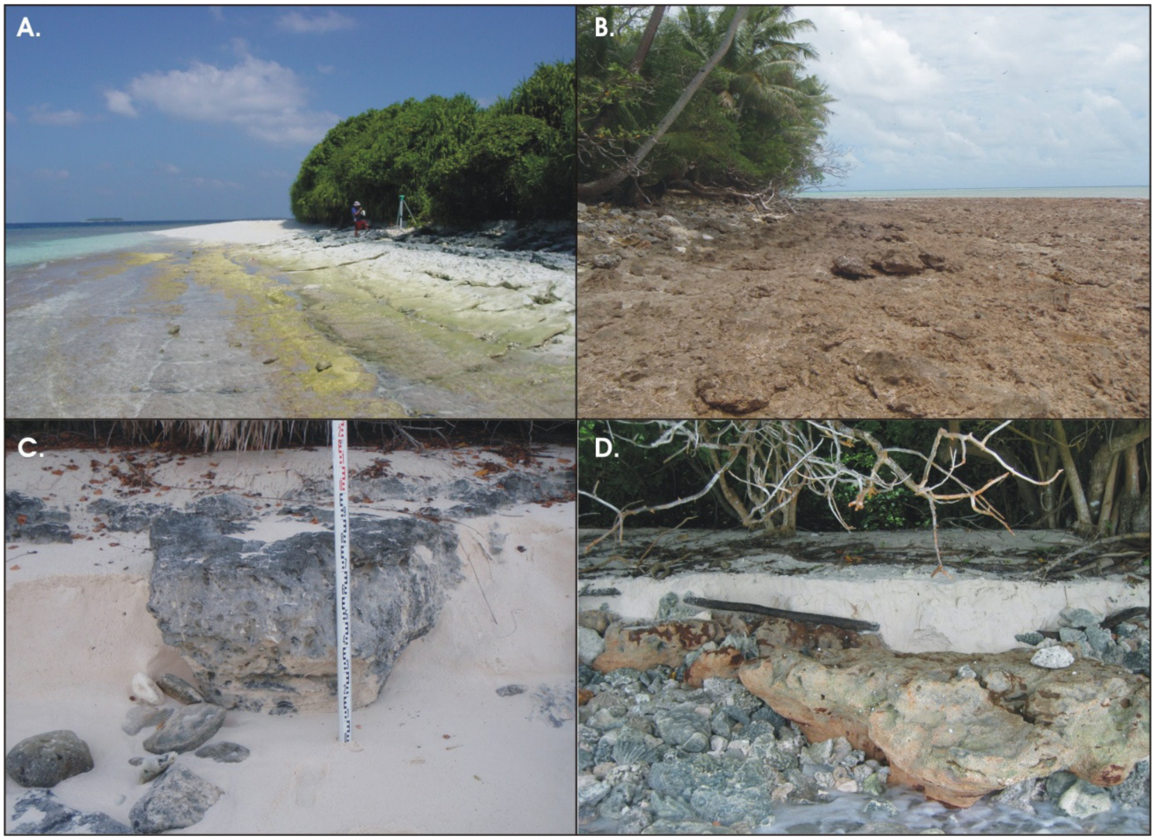

Figure 10. Examples of consolidated sediments on islands of Baa Atoll. A) Continuous beachrock surrounding the Keyodhoo Island shoreline. B) Conglomerate rock that outcrops on island shorelines. C) Cay sandstone outcropping on island shoreline and typical of massive rock located beneath the island surface in some islands. D) Phosphate rock outcropping on the Keyodhoo shoreline. Note brown colouration of rock. Phosphate rock is found beneath the island surface on a number of islands in Baa Atoll.

Beachrock is prevalent on many islands in the atoll. (Fig. 10A). Distinctive in its intertidal elevation and in the slope that mirrors the contemporary beach, on some islands beachrock forms near continuous deposits that encircle islands (e.g, Keyodhoo, Hulhudhoo, and Udoodhoo). In these islands beachrock is seasonally buried by the movement of the contemporary beach. Beachrock is also found detached from island shorelines where it documents previous island positions on the reef platform.

Conglomerate. Lithified deposits of gravel and sand occur on the high energy shores of a number of peripheral islands (Fig. 10B). Such deposits do not possess the sloping surface characteristic of beachrock and are interpreted as cemented high energy deposits or even cemented gravel ridges that have subsequently been eroded. Examples can be found on Aidhoo and Gaaviligili. Gardiner (1903) also described this deposit on Maamaduvvari although at the time he interpreted this rock as evidence for higher sea level.

Cay sandstone can form at the level of the water table beneath islands. Cay sandstone consists of cemented bioclastic sand-size sediments and is distinguished from beachrock by near horizontal bedding. In Baa Atoll cay sandstone is not found on all islands but where it is present can be more than 1 m thick (Fig. 10C).

Phosphate rock can occur and forms at the water table and within the soil horizons of islands in Baa Atoll. Phosphate rock also comprises cemented reefal bioclastic sediments; however, the grains are replaced by phosphate minerals (Hopley, 2011). Phosphate rocks in Baa Atoll are distinguished by their light orange to brown colouration (Fig. 10D). Island cores extracted from a range of islands indicate that phosphate rock is not ubiquitous. However, where phosphate rock occurs it can form continuous cemented layers that underlie the island surface. For example, on Dhakandhoo and Thiladhoo islands on the west and eastern sides of the atoll phosphate rock is found as a continuous layer beneath the island. On Keyodhoo and some other islands, erosion of the shoreline has exposed phosphate rocks which outcrop at the shoreline. Investigations from Dhakandhoo show that the phosphate layer has been mined by local communities for the purposes of agricultural fertilisation.

Island Evolution

The detailed evolution of reef islands in Baa Atoll has been investigated by Kench et al. (2005) based on detailed coring and radiometric dating of island sediments. A summary of the radiometric dates and chronostratigraphy of three islands is presented in Figure 11 and Table 5. The data show that island sediments are of mid-Holocene age. Chronostratigraphic analysis of the dated sediments relative to the underlying reef provides insights into the temporal development of the islands in Baa Atoll. A three-phase model of island formation has been proposed (Kench et al., 2005). First, the small reef platform islands appear to have been deposited over infilled faro lagoons (velu). As reef growth approached sea level they encountered wave base, which provided a process mechanism to flush reefal sediments into lagoons. Radiometric ages of suggest velu sediments were deposited approximately 5,500 to 5,000 yBP. Second, island accumulation across velu deposits was initiated approximately 5,000 yBP. The narrow range of ages of island sediments (5,125 ± 61 to 3,736 ± 57 yBP), particularly on Dhakandhoo and Hulhudhoo indicate that islands accumulated rapidly with deposition of the vegetated core of islands effectively complete by 4,000 yBP. The third phase spans the past 4,000 years and is characterised by cessation of island building. Lithification of sediments as cay sandstones, phosphate rocks and beachrock has assisted in the stabilisation of islands. Further dates on reefal materials (Tables 1 and 5) show that continued vertical reef growth occurred over the past 4,000 years which would have progressively closed down the process window from that under which islands were constructed. The interaction between vertical reef growth on the outer reef and seasonal oscillations in beach position, which constrained vertical reef development on the inner reef, is responsible for development of nearshore moat that surrounds reef islands.

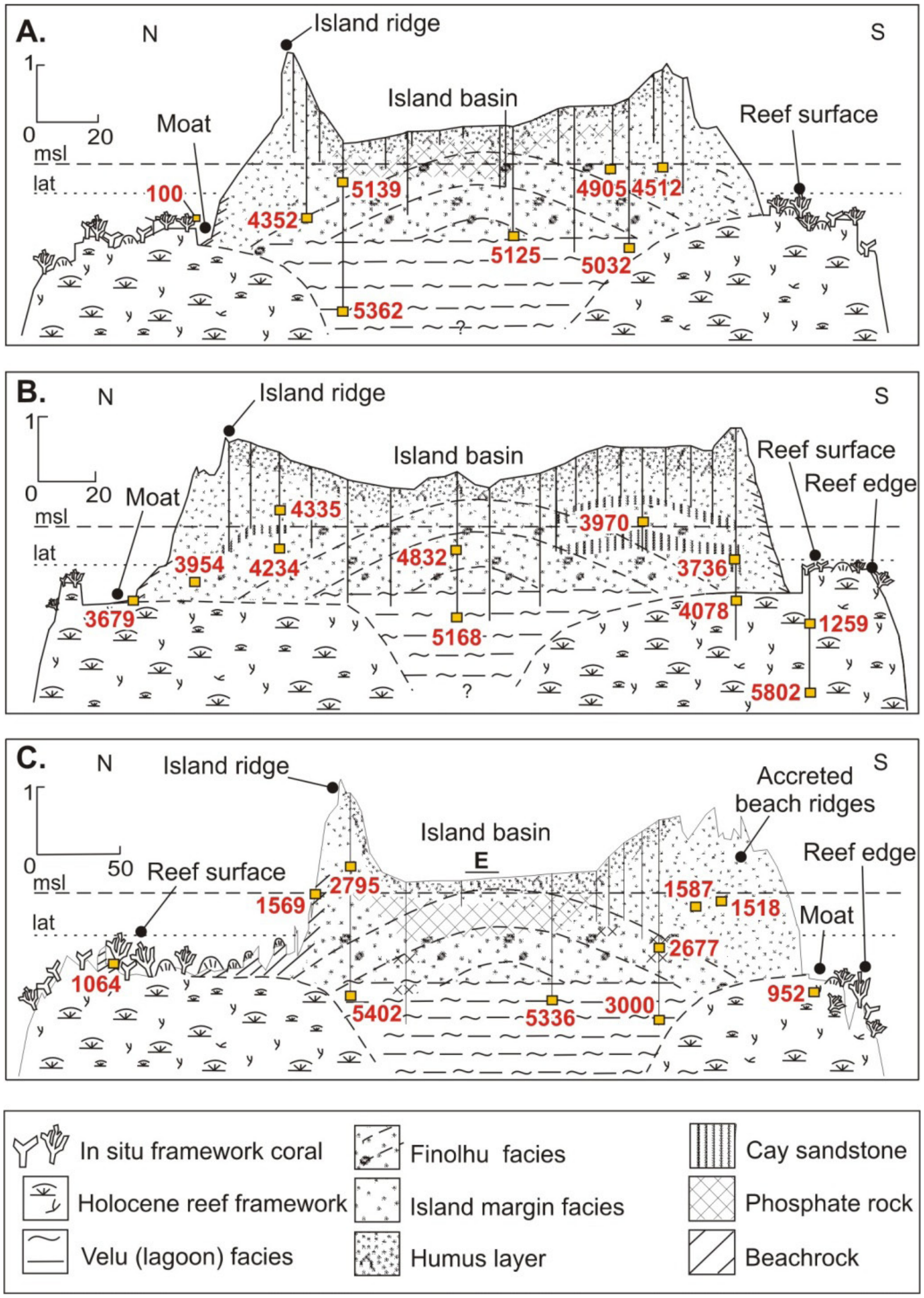

Figure 11. Morphostratigraphy of reef and island cross sections, Baa Atoll. Location of islands shown on Figure 2. A) Dhakandhoo B) Hulhudhoo C) Thiladhoo. Conventional radiocarbon ages shown in red are in correct stratigraphic position (see Table 5 for error terms).

Table 5. Radiocarbon dates from detailed morphostratigraphic studies of three islands in Baa Atoll, Maldives.

Island	Laboratory code	Facies designation and material	Depth relative to MSL(m)	Conventional age (yr B.P.)	Calibrated age range (95.4% probability) (cal. yr B.P.)
Dhakandhoo	Wk 11293	Velu facies: sand	–0.29	5139 ± 62	5550–5200
	Wk 11294	Velu facies: sand	–2.55	5362 ± 63	5730–5440
	Wk 11295	Velu facies: sand	–1.58	5032 ± 60	5410–5000
	Wk 11296	Finolhu facies: sand	–1.23	5125 ± 61	5530–5130
	Wk 11297	Finolhu facies: sand	0.05	4905 ± 51	5230–4860
	Wk 12661	Finolhu facies: sand	–0.05	4512 ± 42	4680–4440
	Wk 12662	Finolhu facies: sand	–1.18	4352 ± 44	4880–4250
	Wk 12660	Dead *in situ* coral	–0.92	105 ± 0.5	Modern
Hulhudhoo	Wk 12097	Finolhu facies: sand	0.26	4335 ± 46	4460–4210
	Wk 11298	Finolhu facies: sand	–0.29	4234 ± 52	4320–3970
	Wk 11299	Finolhu facies: sand	–0.34	4832 ± 59	5140–4790
	Wk 11300	Velu facies: sand	–1.29	5168 ± 62	5560–5260
	Wk 11301	Finolhu facies: sand	–0.51	3736 ± 57	3640–3350
	Wk 11302	In situ reef rock	–1.17	4078 ± 70	4140–3720
	Wk 11303	Reefal sand	–1.80	1259 ± 47	780–570
	Wk 11304	In situ coral	–2.50	5802 ± 60	6210–5910
	Wk 12663	In situ fossil *Porites*	–0.26	3679 ± 40	3550–3340
	Wk 12664	Finolhu facies: sand	–0.145	3970 ± 40	3950–3720
	Wk 12665	Island-margin sand	–1.13	3954 ± 40	3930–3700
Thiladhoo	Wk 11305	Finolhu facies: sand	–0.79	2677 ± 57	2340–2050
	Wk 11306	Velu facies: sand	–1.84	3000 ± 55	2750–2430
	Wk 11307	Island-margin sand	0.40	2795 ± 54	2540–2160
	Wk 11308	Velu facies: sand	–1.52	5402 ± 54	5750–5480
	Wk 11309	Beachrock	0.18	1064 ± 45	630–460
	Wk 11310	Beachrock	0.00	1569 ± 44	1100–890
	Wk 11311	In situ fossil *Porites*	–1.09	952 ± 46	530–330
	Wk 12666	Velu facies: sand	–1.52	5336 ± 43	5680–5460
	Wk 12667	Island-margin sand	–0.14	1518 ± 37	1030–840
	Wk 12668	Island-margin: sand	–0.39	1587 ± 36	1100–920

Note: Radiocarbon dates obtained from the Radiocarbon Dating Laboratory, University of Waikato, New Zealand. Ages calibrated by using OxCal version 3.5 (Bronk Ramsey, 2001) with the marine data set (Stuiver et al., 1998) and Delta-R value of 132 ± 25 as best estimate for the central Indian Ocean reservoir effect (Southon et al., 2002).From Kench et al., (2005).

It is evident that a major phase of island formation occurred in Baa Atoll between 5,000 and 4,000 yBP. Additional near surface radiocarbon dates from a number of other islands are consistent with this interpretation (Table 6). Comparison of the chronology of island formation with the established sea level curve in Baa Atoll provides further insights into the relationship between sea level, island formation and island persistence in the Holocene. First, evidence from the reef growth record (Fig. 6) suggests islands formed at sea level over slightly submergent reef platforms. This implies that the water depth and process window for island accumulation across reef surfaces was higher during the period of island formation. Second, emergent microatolls indicate that sea level rose to 0.5 m above present 2,000-4,000 years ago. This post-dates island formation and indicates islands in Baa Atoll have been subject to higher sea levels in the mid- to late Holocene. During this period continued vertical reef growth occurred. The combination of vertical growth of the outer reef and late Holocene fall in sea level has reduced the magnitude of the process window that can access and force morphological change of reef islands.

Table 6. Sundry near surface dates from a range of reef islands in Baa Atoll, Maldives.

Island	Laboratory code	Facies designation and material	Depth relative to MSL(m)	Conventional age (yr B.P.)
Mendhoo	WK 7078	Beach sand	-	1370 ± 50
	Wk 6175	West island surface	-0.35	2300 ± 60
	Wk 5839	Central island	-0.78	3520 ± 60
Udoodhoo	Wk 6337	Beach sand	-	1390 ± 50
	Wk 5829	Central east	-0.8	4500 ± 60
	Wk 6170	Central west	-0.64	4710 ± 70
	Wk 6331	Central east	-0.54	4960 ± 60
Hanifaru	Wk 6338	Centre of island	0.21	1500 ± 50
Nelivaru	Wk 6173	Centre	2.3*	1560 ± 50
	Wk 6336	Beach	-	1570 ± 50
	Wk 6174	Centre	2.9*	2040 ± 50
Bodufinholhu	Wk 6168	Centre of island	0.17	1590 ± 50
Hithaadhoo	Wk 6166	Centre and northern	2.01*	1610 ± 60
Hibalhidhoo	Wk 5834	West side island	-0.48	1630 ± 50
	Wk 5833	East side island	-0.37	1850 ± 50
Muthaafushi	Wk 6172	East side island	-0.33	1770 ± 50
Fonimagoodhoo	Wk 7079	North	1.14*	1910 ± 60
	Wk 7082	South,	0.75*	2260 ± 60
Nibiligaa	Wk 6335	Central island	-0.31	1980 ± 50
	Wk 5830	Central island	-0.64	2240 ± 50
Fares	Wk 6171	Eastern island	-0.45	1980 ± 60
	Wk 5840	Central east	-0.55	3200 ± 60
Maamaduvvari	Wk 6167	West island	-0.54	1630 ± 50

	Wk 7080	South island surface	-0.05	2160 ± 60
	Wk 5836	Southeast	-0.24	2270 ± 60
Olhugiri	Wk 6333	South side island	0.43	2010 ± 60
	Wk 5832	South side island	-0.72	2040 ± 60
	Wk 5831	Centre	0.50	2870 ± 60
Maaddoo-hulhudhoo	Wk 6329	Beach	-	2060 ± 50
	Wk 6332	Coral in phosphate rock	-	4220 ± 80
	Wk 6165		0.12	4850 ± 80
Maaddoo	Wk 6330	Western island	-0.33	2250 ± 60
	Wk 6334	Northeast	-0.2	2280 ± 60
	WK 5837	Northeast island	0.52	2870 ± 60
Dhoogadu finolhu	Wk 7081	Cay sandstone	-	2190 ± 60
Gemendhoo	Wk 5838	Central island	-0.2	2880 ± 60
Aidhoo	Wk 6339	Central island	0.44	2920 ± 50
	Wk 5835	Central island	-0.06	3130 ± 60
Kamadhoo	Wk 6169	Southeast island	1.88*	3910 ± 60

Note: Radiocarbon dates obtained from the Radiocarbon Dating Laboratory, University of Waikato, New Zealand. From Ali, 2000.

CONCLUSIONS

Historically there have been few investigations of the geomorphology of the reefs and islands of Baa Atoll. However, over the past decade investigations of islands in Baa Atoll have significantly increased understanding of the geomorphology, morphodynamics and evolution of reefs and islands.

Studies show a significant variation in the morphology and sedimentary character of islands. There is also a distinct spatial distribution of islands with most peripheral islands found on the east to southeastern atoll rim. Lagoon islands also tend to be located in the central and eastern side of the atoll.

This pattern of island distribution can be explained by net wave energy inputs to the atoll. Calculations of a gross wave energy balance across the atoll (Kench et al., 2006) identify a distinct west to east energy gradient which has implications for reef island presence, shape and location on reef platforms and provides quantitative support for Gardiner's (1903) and Sewell's (1936b) hypothesis that exposure to wave energy can account for the presence of islands. Island formation is constrained on the exposed western reef rim as a result of continual high magnitude wave energy inputs that sweep sediments across and off the reef platforms. Consequently, the few islands that do occur on the western atoll rim are either found on the leeward locations of broad reef flats or are composed of gravel. The more sheltered, lower energy lagoonal reef platforms combined with the circular shape of these reef platforms has two effects: i) it ensures reef top sediments are trapped on reef surfaces through oscillating monsoonal conditions, thus contributing to island building, and ii) these islands occupy a large proportion of the available reef surface. In contrast, the eastern atoll rim is dominated by a net easterly energy balance (of lower magnitude than the western atoll rim) and the most exposed islands are located on the western sides of reef platforms.

Variations in the sedimentary character of islands are a function of the grade of sediment available for island building and hydrodynamic energy. Consequently, islands in exposed high-energy settings, close to the reef edge of the atoll rim are typically composed of gravel or rubble size material. In contrast, lagoonal and leeward reef islands are composed of sand-size sediments.

Baa Atoll is the location of the first systematic monitoring programme established to examine the morphological adjustment of atoll islands. Seasonal monitoring of the island shorelines has shown that islands are morphologically dynamic and are able to adjust their position around the vegetated core of islands in response to variations in incident wave processes (Kench and Brander, 2006). Monitoring has also established the impact of extreme events on the morphological adjustment of islands (Kench et al., 2006, 2007, 2008).

Studies of the Holocene evolution of the reefs and islands show the reefs underwent a rapid phase of development between 8,000 and 6,000 yBP. Islands are of mid-Holocene age and formed in a narrow window 5,000-4,000 yBP across infilled lagoons. Since formation the vegetated island cores have remained relatively stable allowing formation of cay sandstone and phosphate rocks.

Collective studies of the islands of Baa Atoll have important implications for the future of coral reef islands. In particular, confirmation of a sea level highstand 2,000-3,500 yBP allows critical re-evaluation of the relationship between sea level, reef growth and island formation. In the Maldives islands formed 5,000 – 4,000 years ago (Kench et al., 2005) and persisted as sea level rose to 0.5 ±0.1 m above present during the highstand ca 2,000-4,000 cal yBP. Consequently, Maldivian islands provide a geological analogue that demonstrates reef islands are capable of accommodating rising sea level comparable to that projected for the next century.

While studies of the reef islands of Baa Atoll have provided significant new insights into reef island formation and change, which have global application, extrapolation of the results to other atolls in the Maldives should be undertaken with caution. Baa Atoll is an open atoll with numerous patch reefs. Islands typically occupy the surface of these patch reefs. Consequently observations are likely to extend to similar structured atolls. However, the Maldives archipelago is comprised of 26 atolls many of which have differing reef structure and which straddle 850 km of latitude. Consequently, the reefs and islands are likely to reflect latitudinal variations in morphology and morphodynamics. More extensive studies of islands throughout the archipelago are required to develop a comprehensive understanding of the diversity of reef and island types.

REFERENCES

Agassiz, A.
1903. The Coral Reefs of the Maldives. Memoirs of the Museum of Comparative Zoology, Harvard College, 29, 1-68.
Ali, M.
2000. Reef island geomorphology: formation, development and prospective of islands in Eta atoll, South Maalhosmadulu, the Maldives. Unpublished PhD thesis. The University of New South Wales, Australia, 344 p.
Aubert, O., and Droxler, A.
1992. General Cenozoic evolution of the Maldives carbonate system (equatorial Indian Ocean). Bulletin des Centres de Recherches Exploration-Production Elf Aquitane, 16, 113-136.
Belopolsky, A. and Droxler, A.
2003. Imaging Tertiary carbonate system – the Maldives, Indian Ocean: insights into carbonate sequence interpretation. *The Leading Edge*, p. 646-652.
Bronk Ramsey, C.
2001. Development of the radiocarbon program OxCal. *Radiocarbon*, 43, 355–363.
Cameron, A.
2002. Spatial differences in reef island morphology and sediment texture. Unpublished Honours dissertation, The University of Auckland, 84 p.
Camoin, G.F., Montaggioni, L.F., and Braithwaite, C.J.R.
2004. Late glacial to post glacial sea levels in the Western Indian Ocean. *Marine Geology,* v. 206, p. 119-146.
Darwin C.
1842. Darwin, C. 1842. The structure and distribution of coral reefs. Smith Elder, London
Duncan, R.A., and Pyle, D.G.
1988. Rapid eruption of the Deccan flood basalts at the Cretaceous/Tertiary boundary. *Nature*, 333, 841-843.
Duncan, R.A., Hargreaves, R.B.
1990. 40Ar/39Ar geochronology of basement rocks from the Mascarene plateau, the Chagos Bank, and the Maldives Ridge. Proceedings Ocean Drilling Programme, Scientific Results, 115, 43–51.
Gardiner, J.S.
1903. The Fauna and Geography of the Maldives and Laccadives Archipelagoes. Cambridge University Press, London and New York.
Gischler, E., Hudson, J.H., and Pisera, A.
2008. Late Quaternary reef growth and sea level in the Maldives, Indian Ocean. *Marine Geology*, 250, 104-113.
Hass, H.
1965. Expedition into the unknown: a report on the expedition of the research ship Xarifa to the Maldives and Nicobar islands. Hutchison and Co, London.

Hopley, D.

2011. Phosphatic cay sandstone. In Hopley D. (Ed.) Encyclopedia of Modern Coral Reefs: Structure Form and Process. Springer, The Netherlands, p. 798-801.

Kench, P.S., McLean, R.F. and Nichol, S.L.

2005. New model of reef-island evolution: Maldives, Indian Ocean. *Geology*, 33:145-148.

Kench, P.S., Brander, R.W., Parnell, K.E. and McLean, R.F.

2006. Wave energy gradients across a Maldivian atoll: implications for island geomorphology. *Geomorphology*, 81, 1-17.

Kench, P.S. and Brander, R.W.

2006. Response of reef island shorelines to seasonal climate oscillations: South Maalhosmadulu atoll, Maldives. *Journal of Geophysical Research*, 111, F01001, doi:10.1029/2005JF000323.

Kench, P.S., McLean, R.F., Brander, R.W., Nichol, S.L., Smithers, S.G., Ford, M.R., Parnell, K.E. and Aslam, M.

2006. Geological effects of tsunami on mid-ocean atoll islands: The Maldives before and after the Sumatran tsunami. *Geology*, 34, 177-180.

Kench, P.S., McLean, R.F., Nichol, S.L., Smithers, S.G., and Brander, R.W.

2007. Impact of the Sumatran tsunami on the geomorphology and sediments of reef islands: South Maalhosmadulu atoll, Maldives. *Atoll Research Bulletin*, No. 544, 105-134.

Kench P.S., Nichol S.L., Smithers S.G., McLean R.F. and Brander R.W.

2008. Tsunami as agents of geomorphic change in mid ocean reef islands. *Geomorphology*, 95, 361-383.

Kench P.S., Smithers S.L., McLean R.F. and Nichol S.L.

2009a. Holocene reef growth in the Maldives: evidence of a mid-Holocene sea level highstand in the central Indian Ocean. *Geology*, 37(5), 455-458.

Kench, P.S., Parnell, K.E., Brander, R.W.

2009b. Monsoonally influenced circulation around coral reef islands and seasonal dynamics of reef island shorelines. *Marine Geology*, 266, 91–108.

Kench, P.S., Brander, R.W., Parnell, K.E., O'Callaghan, J.

2009c. Seasonal variations in wave characteristics around coral reef island, South Maalhosmadulu atoll, Maldives. *Marine Geology*, 262, 116–129.doi.10.1016/j.margeo.2009.03.018.

Kench, P.S.

2011. Maldives. In Hopley D. (Ed.) Encyclopedia of Modern Coral Reefs: Structure Form and Process. Springer, The Netherlands, p. 648-653.

Montaggioni, L.F.

2005. History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors. *Earth Science Reviews*, 71, 1-75.

Naseer, A., and Hatcher, B.G.

2004. Inventory of the Maldives coral reefs using morphometrics generated from Landsat ETM+ imagery. *Coral Reefs*, 23, 161-168.

Nichol, S.L. and Kench P.S.
2008. Sedimentology and preservation of carbonate sand sheets deposited by the December 2004 Indian Ocean tsunami: South Baa atoll, Maldives. *Sedimentology*, doi:10.1111/j.1365-3091.2007.00941.x

Purdy, E.G., and Bertram, G.T.
1993. Carbonate concepts from the Maldives, Indian Ocean. American Association of Petroleum Geologists Studies in Geology, 34, 56 p.

Sewell, R.B.S.
1936a. An account of Addu Atoll. Scientific Reports, John Murray Expedition 1933-1934.1, 63-93.

Sewell, R.B.S.
1936b. An account of Horsburgh or Goifurfehendhu Atoll. Scientific Reports, John Murray Expedition 1933-1934.1, 109-125.

Smithers, S.G., and Woodroffe, C.D.
2000. Microatolls as sea level indicators on a mid-ocean atoll: *Marine Geology*, 168, 61-78.

Southon, J., Kashgarian, M., Fontugne, M., Metivier, B., and Yim, W.
2002. Marine reservoir corrections for the Indian Ocean and Southeast Asia: *Radiocarbon*, 44, 167-180.

Stuiver, M, Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., van der Plicht, J., and Purk, M.
1998. INTCAL98 radiocarbon age calibration, 24,000-0 cal BP: *Radiocarbon*, 40, 1041-1083.

Stoddart, D.R. (Ed.)
1966. Reef studies at Addu atoll, Maldive Islands. Preliminary results of an expedition to Addu atoll in 1964. *Atoll Research Bulletin*, 116: 1-122.

Tiwari, V.M., Grevemeyer, I., Singh, B., and Phipps Morgan, J.
2007. Variation of effective elastic thickness and melt production along the Deccan-Reunion hotspot track. *Earth and Planetary Science Letters*, 264, 9-21.

Wallace, C.C., and Zahir, H.
2007. The ‘Xarifa’ expedition and the atolls of the Maldives 50 years on. *Coral Reefs*, 26, 3-5.

Woodroffe, C. D.
1993. Morphology and evolution of reef islands in the Maldives. 7th International Coral Reef Symposium, Guam, Marine Laboratory, University of Guam, p. 1217-1226.

Woodroffe, C.D.
2005. Late Quaternary sea-level highstands in the central and eastern Indian Ocean: A review. *Global and Planetary Change*, 49, 121-138.

BENTHIC ALGAL AND SEAGRASS COMMUNITIES IN BAA ATOLL, MALDIVES

BY

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ABSTRACT

The present survey was undertaken to provide the first census of the marine flora (macroalgae and seagrasses) of Baa Atoll, one of the 26 Maldivian atolls, and to serve along with the macro-fauna biodiversity inventories for conservation purposes. Species collection and inventories have been conducted at 27 sites covering the widest selection of habitats recognized based on satellite images including islands shorelines, reef flats, faros, patch reefs, passes as well as shallow and deep outer reef slopes. A total of 405 specimens were collected and 176 species representing 10 Phaeophyceae, 58 Chlorophyta, 108 Rhodophyta and two seagrasses were identified. The lagoon patch reefs and the oceanic reef slopes were the most diverse geomorphological habitat types and displayed the highest species richness with 38 spp. All lagoon sites shown a similar richness compared to each other with an average species number of 26 spp, while the deep lagoon floor and the seagrass beds in oceanic-exposed reef flats were the less species-rich habitats. The most common species, occurring at all visited sites, were *Tydemania expeditionis* and *Halimeda minima* and the most species rich genera appeared to be *Halimeda* and *Caulerpa*. No community structure nor strongly supported species assemblages associated to geomorphological habitat types was found.

Previous lists available for other Maldivian atolls listed 208 algal species. Sixty of these records were found in Baa Atoll while 113 of the species recorded in the present study represent new records for the Maldives bringing the total number of algal species to 321. The resulting species list shows that the Maldivian algal flora is typically tropical and most of the species belong to the Indo-Pacific biogeographic province. In this paper, we give a general description of the representative macrophyte communities of Baa Atoll in relation to the geomorphology of reefs.

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INTRODUCTION

Very limited information is available on Maldives archipelago marine flora despite a large number of oceanographic expeditions carried out in the region. Most of the records are based on sporadic studies. The first phycological taxonomic records were published from the limited biological material collected during the expeditions of J.S. Gardiner in the early 1900s (Gardiner, 1903) and studied by Barton (1903), Foslie (1903, 1907), and Weber and Foslie (1904). The Sealark Expedition in 1905 resulted in Gepp and Gepp's (1904) and Weber-van Bosse's (1914) records of some Chlorophyta ("green algae") and Rhodophyta ("red algae"). Newton (1953) published only one seaweed record from the J. Murray expedition 1933-1934. At this time the knowledge of the Maldivian algal flora was restricted to 24 species including 17 Rhodophyta, five Chlorophyta and two Pheaophyceae ("brown algae"). During the expedition led by D.R. Stoddart from Cambridge in 1964, Sigee (1966) sampled land and marine vegetation at Addu Atoll. The preliminary results of the Addu Atoll expedition were published in *Atoll Research Bulletin* by Stoddart (1966). The Sigee collection was studied by Tsuda and Newhouse (1966) who published a taxonomic list, adding significantly to the total species number of macroalgae with 37 Rhodophyta, 30 Chlorophyta , nine Phaeophyceae and seven cyanobacteria ("bluegreen algae"). Extensive collections of benthic macroalgae were made at nine Maldivian atolls during Cruise B and Cruise 5 of the R/V *Te Vega* Expeditions in 1964 by H.E. Hackett and M.J. Wynne respectively. Hackett (1969) studied his own collection for his PhD dissertation as well as material collected by C. Rhyne in 1967 at Addu Atoll during the U.S. Navy Biological Expedition to the Chagos Archipelago. Based on these collections additional records were published in Hollenberg's (1968a, b) monographs and Aregood and Hackett (1971) described a new species of Rhodophyta (*Dictyurus maldiviensis* Hackett & Aregood). Later, Hackett (1977) published the most comprehensive catalogue of the Maldivian marine algae with 248 records including 136 Rhodophyta, 74 Chlorophyta, 17 Phaeophyceae and 21 Cyanobacteria. A number of these records however were identified only at the genus level. A year later, Titlyanova and Butorin (1978) published a short list of macroalgae (18 taxa) from two atolls of the Maldives. Finally Wynne (1993) published a list of 50 species based on his own collections including the description of *Bangia halymeniae* Wynne from Malé Atoll.

In 2009, before the Baa expedition, the most updated compilation of the marine flora of the Maldives was available from "algaebase.com" and listed 120 Rhodophyta , 70 Chlorophyta, 18 Phaeophyceae and 21 Cyanobacteria records (Guiry and Guiry, 2011).

The present survey was undertaken to provide the first census of the marine flora of Baa Atoll and to serve along with the macro-fauna biodiversity inventories for conservation and identification of biodiversity hot-spots (Hamel and Andréfouët, this issue). We also provide here a general description of the representative macrophyte communities of Baa Atoll in association with the geomorphology of reefs.

SAMPLING SITES AND METHODS

Baa Atoll is situated in the Northern Indian Ocean at latitude 5°11'N and longitude 72°59'E. Baa is one of the 26 Maldivian atolls stretching in a north-south direction off India's Lakshadweep islands. It stands in the Laccadive Sea, about 700 km south-west of Sri Lanka and 400 km south-west of India. Baa Atoll is 42 km long and 32 km wide. The tropical climate is composed of two main seasons: the dry season associated with the winter north-eastern monsoon and the rainy season with strong winds and storms.

The present algal flora and seagrass investigation of Baa Atoll was achieved during May and June 2009 just after the moist south-west monsoon. Surveys were conducted at 27 sites (Fig. 1) covering the widest selection of habitats recognized based on satellite images including islands shorelines, reef flats, faros, patch reefs, passes as well as shallow and deep outer reef slopes. Most of the sites were prospected by SCUBA from 50 m to the surface. The shallow areas including fringing reef flats, patch reefs and shorelines were sampled by snorkelling or reef walk. The sampling effort was standardized and inventory duration at each site was set to 80 min.

All specimens collected were sorted, pressed and air-dried as herbarium vouchers. Photographs of collected specimens were taken *in-situ* and referenced according to herbarium accessions. Samples of selected specimens were pickled in a solution of buffered formalin in seawater (5%) for further anatomical studies. Samples from a selection of taxa were preserved in silicagel or ethanol for further DNA analyses. Since all herbarium specimens were air dried (no formalin), DNA extraction is feasible for further studies if necessary. DNA samples of Dictyotales (*Dictyota* J.V. Lamouroux and *Padina* Adanson) and *Halimeda* J.V. Lamouroux have already been processed and will be included in regional phylogenetic studies.

Overall, specimens were collected to represent a baseline taxonomical collection for the area and the species inventory was compiled in order to reach the more comprehensive species list for Baa Atoll. In agreement with the Maldive Research Center (MRC), the collection was deposited in the phycological herbarium of IRD (Institut de Recherche pour le Développement) in Nouméa (IRD-NOU), New Caledonia.

RESULTS

Representative Algal Communities and Associated Habitats

Seven class habitats have been defined based on geomorphology and most of them were prospected. All habitats could not be sampled with the same effort and some of them, such as seagrass beds or oceanic reef flats, were only visited once (Table 1).

During the present investigation 405 specimens were collected from 27 sites (Fig. 1). A total of 176 species were identified and represented 10 Phaeophyceae, 58 Chlorophyta, 108 Rhodophyta [NB: only the most common red corallines algae were considered] and 2 seagrasses. The taxonomic classification used during this work followed *The catalogue of the benthic marine algae of the Indian Ocean* by Silva and co-authors (1996). The species list is given in Appendix 1. Records belong to 17 orders, 35 families and 94 genera (Table 2).

Table 1. Sampling sites distribution in the seven habitat classes defined based on geomorphology.

Class Habitat	Oceanic reef flat (seagrass)	Lagoon reef flat and slope	Lagoon patch reef	Lagoon reef flat	Deep lagoon	Oceanic reef flat	Oceanic reef slope
number of sites	(1)	(10)	(5)	(3)	(1)	(2)	(5)
Site label	2	1, 5, 6, 8, 12, 13, 21, 22, 24, 28	10, 11, 17, 19, 25	3, 16, 20	23	15, 9	4, 7, 14, 18, 27

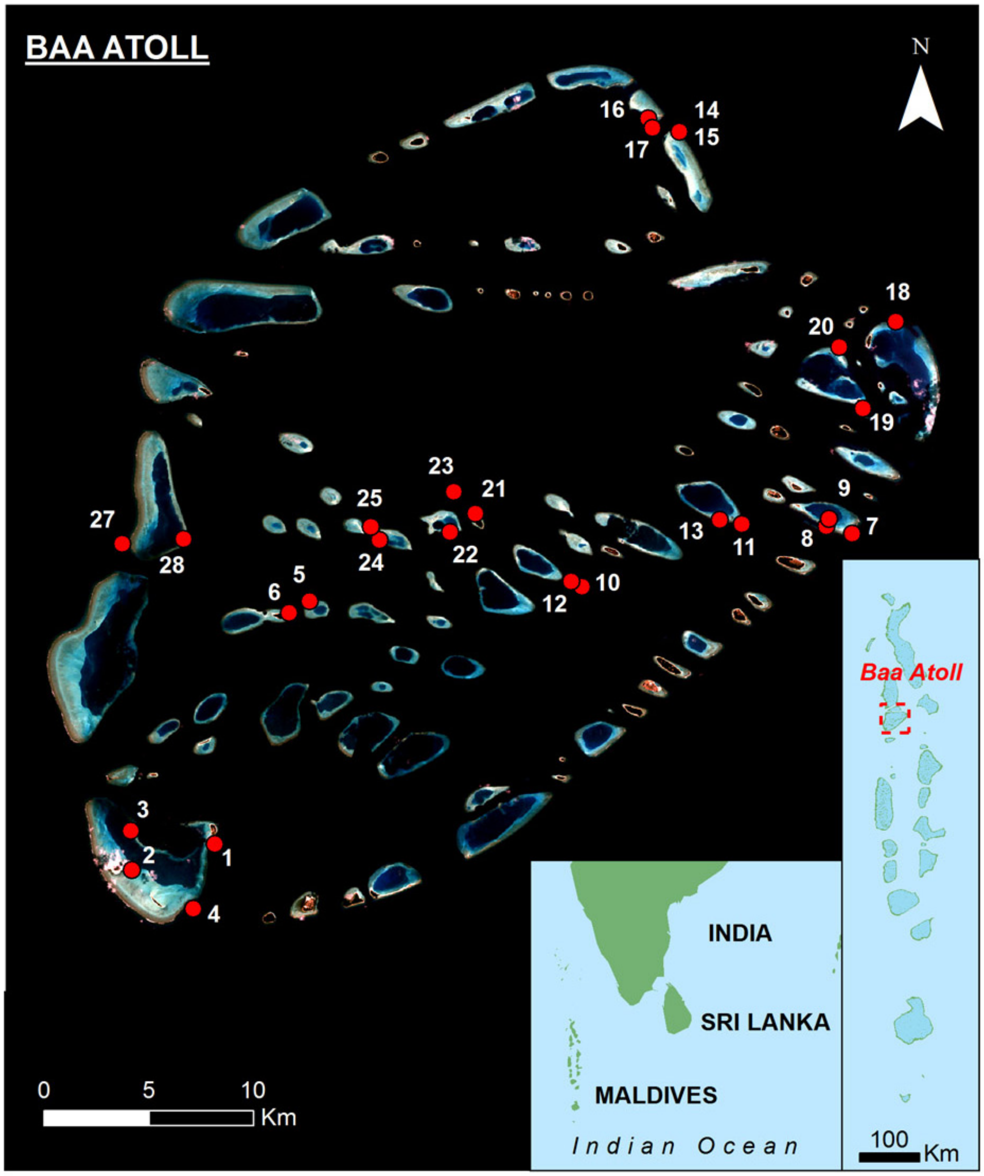


Figure 1. Location of the sampling sites in Baa Atoll.

Table 2. Number of Orders, Families, Genera and Species of macrophytes identified from Baa Atoll

		Orders	Families	Genera	Species
Macroalgae	Rhodophyta	10	22	64	108
	Chlorophyta	5	11	25	58
	Phaeophyceae	2	2	5	10
	TOTAL	17	35	94	176
Seagrasses	Magnoliophyta	1	2	2	2

Most of the specimens have been identified to species level (85 % of the collection), but some of the specimens (15 % of the collection) remain unidentified for lack of reproductive parts or poor sampling. In addition the two seagrasses *Syringodium isoetifolium* (Ascherson) Dandy and *Thalassia hemprechii* (Ehrenberg) Ascherson have been observed forming beds in only a single location (Baa2, Fig.1).

The most species rich genera appeared to be the green algae *Halimeda* and *Caulerpa* J.V. Lamouroux, however surprisingly, no bulbose *Halimeda* spp. were recorded during this survey nor the large Fucales such as *Sargassum* C. Agardh. All the species sampled during the expedition were associated to hard substratum except one: *Boodleopsis pusilla* (F.S. Collins) W.R. Taylor, A.B. Joly & Bernatowicz which occurred on faros' sandy bottoms. (Appendix 2).

Species Richness Distribution in Baa Atoll.

Species richness per site. Species richness per site (Fig. 2) ranged from two at Baa 23 (deep lagoon) to 38 species at Baa 11 (lagoon patch reef) and Baa 7 (oceanic reef slope) (Fig. 1). These two sites, coral built and exposed to strong water movements, were the most diverse and displayed the highest species richness with 38 spp.

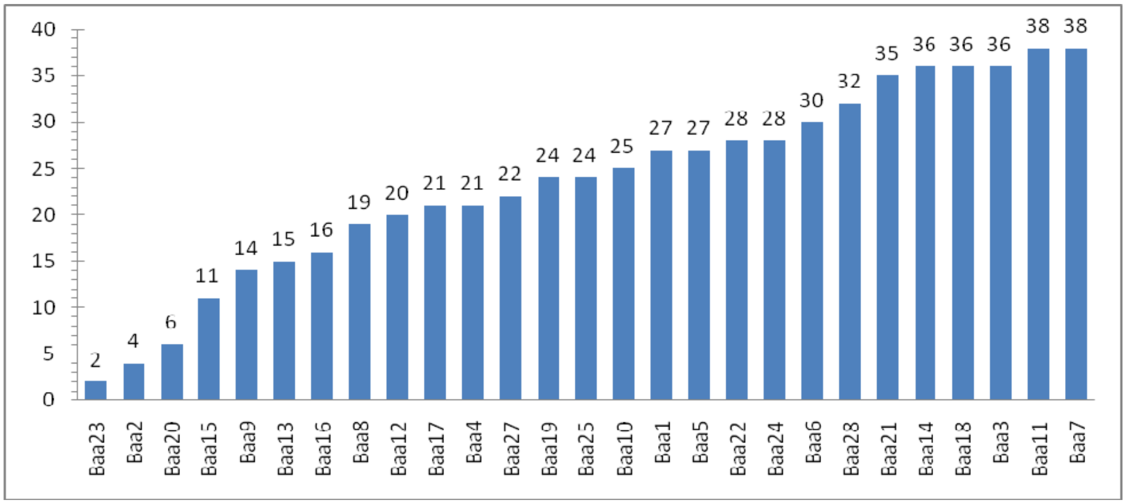


Figure 2. Distribution of species richness per sites.

Because only two species have been collected from the sandy bottom of the deepest lagoon site (Baa 23, 50 m deep) and that Baa 20 (lagoon reef flat) was not properly prospected (no SCUBA on the deeper part), we believe that the data are not reliable enough to report on the species richness of corresponding habitats. The seagrass bed (Baa 2) housed few algal species (four spp, including two coralline rhodoliths). The sandy habitats (Baa 9, 13, 16) and the reef flats (Baa 8, 12, 15) with lower biotope diversity or exposed to very strong current (Baa 17, 19) showed moderate species richness (from 11to 24 spp). For all the other sites algal richness varied between 25 and 35 species (Fig. 3).

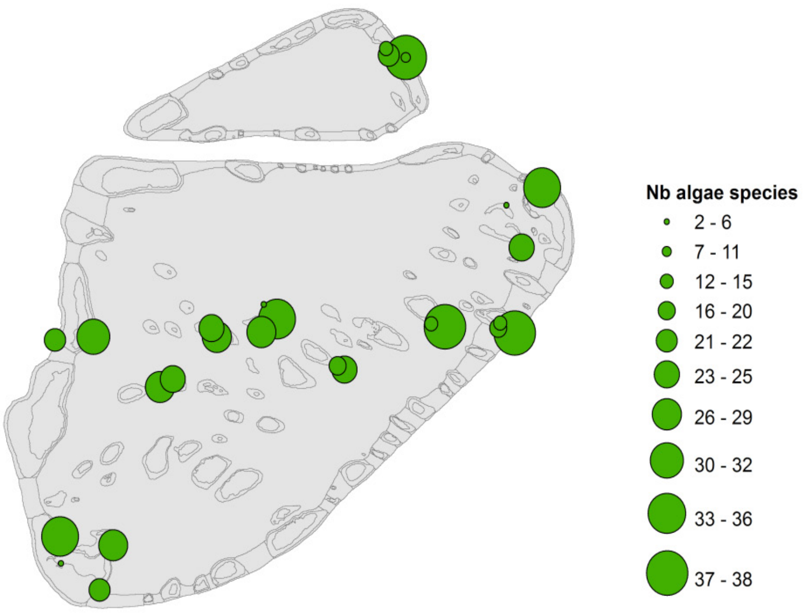


Figure 3.Spatial distribution of the species richness in Baa Atoll.

Species richness per geographic areas. The main features of Maldivian reef complex can be classified into two major classes: (i) the first class includes the atoll rim made of faros with enclosed lagoons delimited by large seaward reef flats, deep outer reef slopes, forereefs, inner slopes and channels/passes; (ii) the second class includes the lagoon structures with mostly faros and enclosed lagoons, reef flats, reef patches, pinnacles and deep lagoon sections.

No contrasting spatial variation could be observed between the different sections of the atoll rim (Table 3). The sampling effort in each geographic area was not strictly similar and could partially affect the resulting values. The average species richness did not contrast strongly from North (21 spp.) to South (28 spp.) and from East (26.2 spp.) to West (27 spp.). Nevertheless, the lowest species richness was observed in the northern rim section. No contrasting difference could be found between the average species richness of the global atoll rim (25.2 spp.) and the lagoonal faros (24.7 spp.).

Table 3. Species richness per geographic area (sites 2 and 20 were excluded because not properly prospected)

Geographic Area	Northern Rim	Southern Rim	Eastern Rim	Western Rim	Atoll Rim	Atoll Lagoon
Number of sites	(4)	(3)	(5)	(2)	(14)	(8)
Site label (BaaX)	14, 15, 16, 17	1, 3, 4	7, 8, 9, 18, 19	27, 28	1, 3, 4, 7,8, 9, 14, 15, 16, 17, 18, 19, 27, 28	5, 6,10, 11,12,13, 21, 22, 23, 24, 25
Average species	21	28	26.2	27	25.2	24.7

Species richness per geomorphological habitat type. Average species richness varied within each geomorphological habitat type (Fig. 4). Figure 4 shows that the deep lagoon and the seagrass beds in oceanic reef flats were the least species rich habitats, while these sites were also the least sampled (*n*=1 site for each of them). All lagoon sites showed a similar richness compared to each other with an average species number of 26 spp. but different sampling efforts (*n= 3* sites for the 'lagoon reef flat', *n=10* sites for the 'lagoon reef flat and slope' and *n= 5* sites for the 'lagoon patch reef'). The oceanic slope showed an average of 30 spp. for the 5 sites.

The spatial distribution of the species varied with bathymetry and some species were observed at a wide range of depths. This is true for instance for the green algae *Caulerpa diligulata*, *Halimeda discoidea*, *Rhipidosiphon javensis, Tydemania expeditionis* and the red *Botryocladia* which were found from 5 m down to 40 m, independently of geographical location. Other species were found to be restricted to deep zones, such as: *Padina okinawensis*, *Cladophora feredayoides*, *Microdictyon okamurae, Caulerpa sedoides,* or cryptic and only in shaded areas such as *Cryptonemia umbraticola* or *Corynocystis prostrata*. Many other species were restricted to shallow waters such as *Valonia aegagropila*, *Dictyurus purpurascens*, *Halymenia actinophysa*, *Hypnea* spp. and *Turbinaria ornata.*

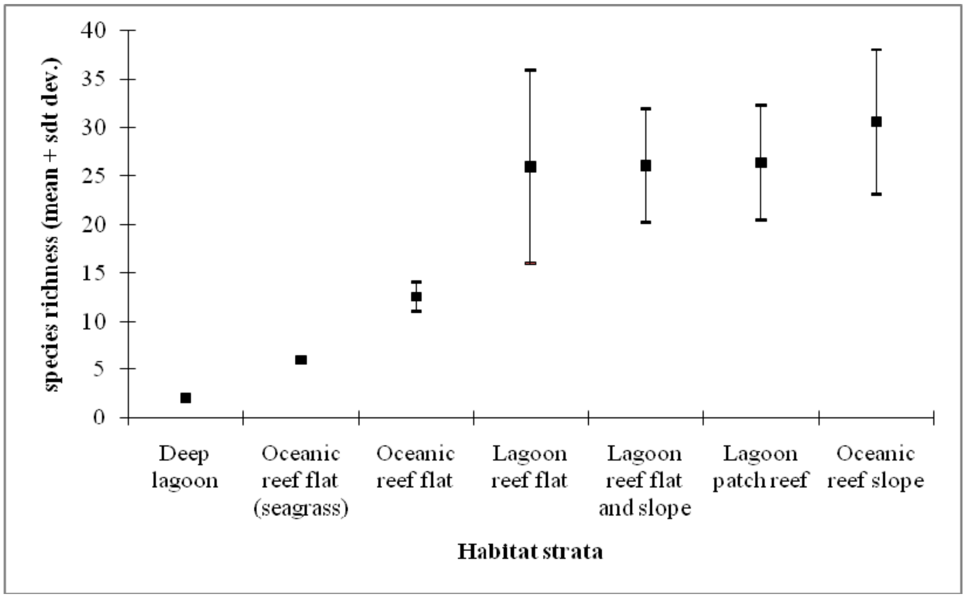


Figure 4. Variation of species richness per habitat type.

Species rarity. Patterns of the algal vegetation in the Baa Atoll were characterized by the dominance of species with very low occurrences at all the prospected sites (Fig. 5). Half of the species (*n*=87) were found in less than 8 % (2/27) of the sites thus revealing a high beta-diversity. No species were present at each of the 27 sites. The most frequent species were the Chlorophyta *Tydemania expeditionis* Weber-van Bosse occurring in 20/27 sites and *Halimeda minima* (W.R.Taylor) Hillis-Colinvaux) present in 19/27 sites. Ninety percent of the species occurred in only 13 sites which represents less than half of the prospected sites. Less than 10% of the species were represented by a single specimen.

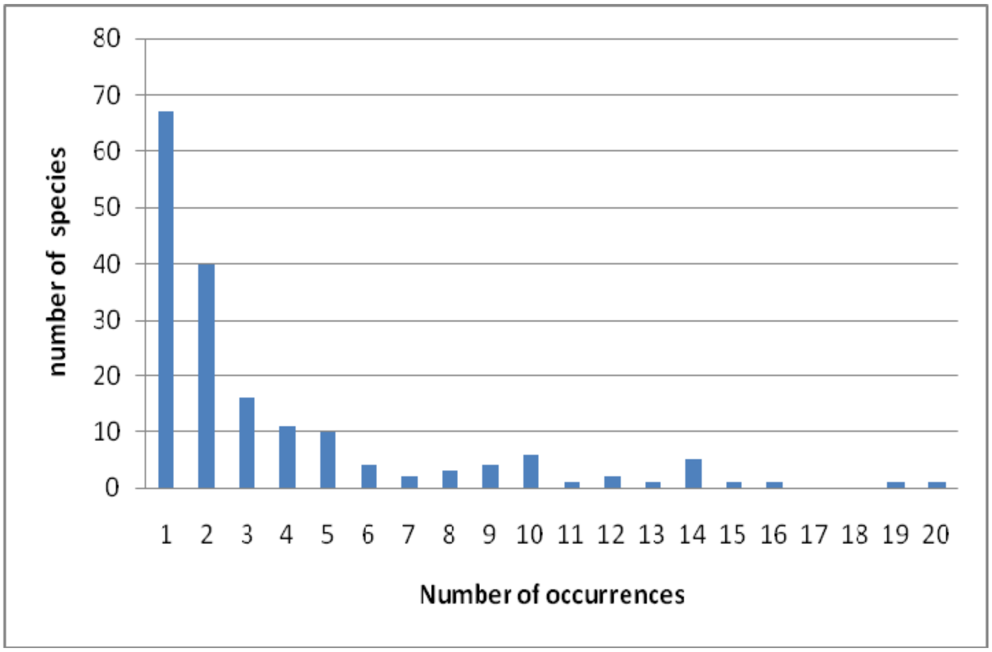


Figure 5. Histogram of species occurrences at the 27 sites.

Main Algal Assemblages.

The most common species are illustrated in Appendix 3.

Algal vegetation on lagoon reef flats and slopes. The algal communities of the Lagoon reef flats and slopes account for a large number of encrusting coralline algae. They are mostly represented either by *Hydrolithon onkodes* which develops thick crusts and a candle-like *Hydrolithon* sp., or branched clumps of *Lithophyllum kotschyanum* mixed with several fleshy species growing in coral crevices. On the reef flats, many species (mostly red algae) grow under the branches of corals. They include the large spreading mats of *Dictyurus purpurascens*, *Hypnea pannosa* and *Hypnea spinella*, isolated clumps of *Galaxaura filamentosa*, *Actinotrichia fragilis*, or the delicate and frondose *Halymenia durvillei*. The green algae were well represented with *Tydemania expeditionis* and several *Halimeda* spp. including the very common and abundant *H. minima*, *H. opuntia* and *H. gracilis* (with tiny segments) while the larger species *H. distorta* and *H. discoidea* were common features of the reef slope's deeper parts.

Some branched *Codium geppiorum* were also observed. Dead corals were colonized by turfs of *Gelidiopsis intricata*, *Champia vieillardii* and *Caulerpa nummularia*. The vegetation on the slopes was scarce, less abundant and dominated by calcareous species such as *Lithothamnium proliferum* and *Halimeda gracilis*. Fleshy algae were less abundant and mostly represented by *Gibsmitha hawaiiensis*, *G. dotyii*, and *Botryocladia skottsbergii*,*Chamaebotrys boergesenii* and *Portieria hornemanii*. Various thin and small fronds of the dark green algae *Rhipiliella* spp. and *Rhipiliopsis* spp. formed small associations in the shady areas with *Corynocystis prostrata* Kaft and *Cryptonemia umbraticola*. The *Caulerpa* spp. were poorly represented in these environments and Phaeophyceae were mainly represented by small Dictyotales such as *Dictyota friabilis* and *Dictyopteris repens*. The large Fucales *Turbinaria ornata* was very rarely found and represented only by juveniles while no *Sargassum* species were observed.

Algal vegetation on lagoon reef flats. The shallow reef flats in the lagoon appeared heterogeneous and some of them in the south-west of the atoll (Baa 3, Fig. 1) showed much more species richness and biomass than those located in the north-eastern section of the atoll. *H. micronesica* and *H. taenicola* were observed only in the north (Baa 20). The vegetation assemblage was similar to that of the lagoon reef flats with numerous encrusted corallines including *Hydrolithon onkodes*, the candle-like *Hydrolithon* sp. and numerous rhodoliths of *Hydrolithon reinboldii*. Various articulated coralline species such as *Amphiroa* spp. formed clumps on the reef top.

Thin and delicate Rhodophyta such as *Hypoglossum* spp., *Nitophyllum* spp. and several *Laurencia* spp., were observed in the crevices of hard substratum along with the very abundant green fan-like *Rhipidosiphon javensis*, the bright green *Anadyomene wrigthii* and *Rhipiliella verticillata*. The typical fan-like *Lobophora variegata* and several large *Dictyota* spp. were found growing on dead corals along with the green sponge-like *Boodlea composita* and the plumose dark green *Bryopsis pennata*.

Algal vegetation in lagoon patch reefs. The species assemblages and richness observed in lagoon patch reefs were relatively variable from one site to another with an average of 25 spp. More than half of the species were present at least three out of five sites visited in this same geomorphologic habitat type. The assemblage was dominated by large green *Tydemania expeditionis*, as well as *Halimeda minima* and *H. opuntia* with a lesser abundance of by *H. cuneata* and *H. gracilis*, the bright green pompom-like *Chlorodesmis fastigiata*, the dark green *Avrainvillea lacerata* and *Asteromenia anastomosans*. *Caulerpa diligulata* occurred at all sites classified in this geomorphological habitat type. Most of the investigated sites showed turf assemblages associated with dead coral including mostly *Gelidiopsis intricata*, *Dictyota humifusa*, and *Champia compressa*. Several species such as *Acanthophora pacifica*, *Caulerpa diligulata*, *Cladophoropsis vaucheriaeformis*, *C. herpestica* were also common component of the oceanic reef slopes assemblages which are described hereafter.

Algal vegetation of the oceanic reef slope. The species assemblages associated with the outer reef slope appeared to be the most diverse and rich, even if the fleshy species were not very diversified. About 30 species were observed in most of the sites. The vegetation was dominated by coralline species especially on the upper part of the slope. Some sections of the outer reef slope were very steep or vertical walls with numerous crevices, overhangs and small caves. Coral walls were encrusted by coralline species and *Peyssonnelia* spp. picturing an attractive mosaic of forms and colors. *Lithothamnion proliferum* was easily recognizable thanks to its pink crust and numerous short knobs. Along the slope several Rhodymeniales including *Leptofauchea* spp. and *Rhodymenia* spp. occurred in caves and crevices as well as *Cryptonemia umbraticola*, *Corynocystis prostrata*, the iridescent *Halichrysis irregularis* and the star–shaped *Asteromenia anastomosans*. Numerous small green species such as *Phyllodictyon anastomosans*, *Rhipidosiphon javensis* and *Rhipilia crassa* were present in the crevices while *Cladophora feredayoides* and *Caulerpa sedoides* were collected from rubbles. Conversely the large *Gibsmithsia hawaiiensis* and *G. dotyii* as well as the delicate *Kallymenia thompsonii*, *Dasya anastomosans* and *D. baillouviana* remained scarce. The most obvious species were the green *Halimeda* spp. (*H. gracilis*, *H. minima* and *H. cuneata*) and *Tydemania expeditionis*. Apart from *Caulerpa diligulata*, which was relatively abundant, the other species of *Caulerpa* (*C. filicoides* and *C. sedoides*) were very inconspicuous.

Algal vegetation of the oceanic reef flat. Oceanic reef flats were not surveyed as frequently as the above described habitats and are represented in this study by only two sites. The species richness was similar from one site to the other with an average of 12 species. Species assemblages however differed strongly. Only two species were common to both sites: the very widespread *Halimeda opuntia* and the West Pacific *Padina okinawensis*. Considering the low sampling effort applied to this geomorphological habitat type during the survey, no definitive features can be described here.

Algal vegetation associated to seagrass beds. Seagrasses are flowering plants belonging to the Cymodoceaceae and Hydrocharitaceae families which are currently classified in the order Alismatales (nomenclature based on phylogenetic studies APGIII, 2009). In tropical regions, they are almost permanently immersed in sheltered marine and estuarine biotopes which offer a suitable substrate for rooting in mud, sand or coarse rubble. In some instances they may also develop into large meadows or beds in deeper lagoon parts down to 40 m deep, or on barrier reefs surrounding lagoon islands. They are remarkable habitats in tropical shallow waters and they often represent keystone ecosystems on sandy bottoms and along shorelines between mangroves and coral reefs.

In Baa, only one site showing typical seagrass habitat was surveyed (oceanic reef flat, Baa 2). The seagrass species diversity was quite low with only two species: *Syringodium isoetifolium* and *Thalassia hemprechii*, forming a dense bed in an area exposed to strong currents. The algal vegetation associated to this meadow was very poor with only four large species including *Halimeda opuntia*, *Valonia aegagropila* and two rhodolith-forming coralline algae: *Neogoniolithon frutescens* and *N. laccadivicum*. More prospection is needed to assess the status of seagrass beds in Baa Atoll.

DISCUSSION

Marine Macrophytes in Baa: General Insights.

A total of 174 macroalgal species were identified from the survey of Baa Atoll. This result does not include the full diversity of coralline algae especially for the encrusting forms which were not fully sampled in the present study. This group is taxonomically difficult and a more comprehensive inventory is needed to properly describe its diversity in Baa. Similarly, microscopic epiphytes and epilithic species have not been exhaustively sampled and studied. A more focused study would most probably reveal a higher diversity. Nevertheless, our results document and acknowledge the ecological rarity typical in tropical ecosystem as well as confirm previous studies conducted in coral reef environments on biodiversity of molluscs and crustaceans (Bouchet et al., 2002). Overall, and in the framework of the Baa expedition, taxonomic results, species distribution and occurrences obtained for the marine flora are similar to those obtained for the other marine groups studied during this expedition (cf. this issue of *Atoll Research Bulletin*).

We carried out a multivariate analysis based on species absence/presence within the 27 studied sites (results available upon request to the first author). Results showed no community structure or strong indication of specific species assemblages associated to geomorphological habitat type. This relative homogeneity could be explained by limited habitat diversity. From its geographical location, Baa atoll appears greatly influenced by shifting monsoonal oceanic conditions. This could generate homogeneous environmental forcing thus limiting habitat diversity and in turn leading to a more or less homogeneously distributed flora at the atoll scale. At reef scale environmental factors are not strictly homogeneous and benthic community assemblages may show spatial heterogeneity (Vroom et al. 2005) which could be the case in Baa. Here, no significant difference in the species richness of the marine flora has been shown among the different areas of the atoll, however the number of restricted species was much higher that the number of species widely distributed. This result questions whether macroalgal communities within a same geomorphological area are ecologically similar.

Cyclones and bleaching events are significant disturbances resulting potentially in a shift from coral dominated to macroalgae dominated reefs (McCook, 1999; Bellwood et al., 2006). However no evidence of algal dominated communities was observed during the expedition, conducted 11 years after the massive 1998 bleaching event that impacted Maldives.

Previous lists available for other Maldivian atolls (Guiry and Guiry, 2011) listed 208 algal species. Sixty three of these records were found in Baa Atoll. Conversely, 113 of the species recorded in the present study represent new records for the Maldives, bringing the total number of algal species to 321 (200 Rhodophyta, 97 Chlorophyta and 24 Phaeophyceae). Comparison with previous studies undertaken in the Maldives show a narrow overlap of the diversity of the species between the different atolls studied.

As observed from the literature and from this study, the Maldivian macroalgal diversity varies from one atoll to another and several very common tropical species have not been recorded during the present survey. Some of the species are seasonal (e.g. *Rosenvingea intricata*) and did not occur in May-June at the time of the survey. Another likely hypothesis is that Baa Atoll does not offer the suitable habitats that support those particular species.

Biogeography

The species list established from this survey shows that the Maldivian algal flora is typically tropical and most of the species belong to the Indo-Pacific biogeographic province. Several species described from the Pacific region were recorded for Baa during this study and represent their first record for the Indian Ocean. They are for example the Dictyotales *Padina okinawensis* described from Southern Japan, the Delesseriaceae *Myriogramme heterostroma* and *M. melanesiensis* originally described from the Solomon Islands and Vanuatu (Western Pacific) and the Halimedaceae *Halimeda xishaensis* from China (Gulf of Tonkin). This suggests that the species geographic distribution is broader than originally thought and underlines the biogeographic affinities of the Maldives marine flora with the tropical West Pacific.

Comparison with floras from adjacent regions is limited due to difference in sampling effort and lack of recently revised species lists. However we compared different archipelogoes from the West Indian Ocean based on species lists available at algaebase.com (Table 4). The proportion of species shared by Baa and other atolls/islands of the Maldives, Laccadives, Chagos, Seychelles and La Reunion was 35.7, 25.5, 17.6, 43.1 and 29.5% respectively. The highest percentage similarity appeared to be with the Seychelles Islands and the other Maldivian atolls. The lowest similarity was observed with the Laccadives (10.57° N and 72.62° E) and Chagos (6° S and 72° E). The reason for such a low similarity despite the geographical location of these Islands (Chagos and Laccadives are located about 600 km off the south and about 250 km off the north of the Maldives, respectively), could be explained by low collecting efforts at these localities resulting in incomplete species lists. A Sorensen's Similarity Index was calculated between the Baa marine flora composition and those of the other localities (Table 4). The highest values were observed for the other Maldivian atolls (0.24). SI values were mostly low and illustrate a species diversity specific to each of the different areas considered. A number of species were not observed in Baa; including Phaeophyceae taxa, among which several species of *Turbinaria* and *Sargassum*. This latter genus was not observed in Baa atoll during the present study nor has it been reported before. Nevertheless, several *Sargassum* species have been mentioned by MRC staff and drift specimens have been collected from other Maldivian atolls. The reason why species of this widespread genus is missing from the Baa inventory warrants further investigation. Grazing pressure, seasonality or very restricted distribution within Baa atoll (i.e. unprospected sites) are plausible hypotheses. The absence of *Sargassum* on Pacific atolls was first discussed by Doty (1954). Tsuda (1976) described the presence of *S. crassifolium* on two Pacific atolls, Ulithi Atoll (Yap State) and Kayangel Atoll (Palau); later Hodgson and McDermid (2000) reported *Sargassum* sp. on Ant Atoll (Pohnpei State). Sterile plants were found in January at Kayangel and fertile plants were found in June and July at Ulithi. The interesting fact is that all *Sargassum* were collected on the northeast (windward side) of the atolls (Tsuda com.pers.).It is interesting that the relative absence of *Sargassum* on Indian Ocean atolls is similar to cases in the Pacific Ocean.

Finally, our results address the issue of representativeness, which is critical in biodiversity management. The little overlap of the macroalgal assemblages between the different atolls demonstrates that, even at small biogeographical scales the spatial heterogeneity is important. This leads to question the concept of "representative protected area" in larger marine ecosystem like the Maldives regions atoll complex.

Table 4. Species richness, Sorensen's similary Index (SI $=2x/2x+y+z$; where x is the number of shared species, y the number of the total species of the first island and z is the total species of the second island or group) and % of common species calculated between species diversity in Baa atoll and other archipelagoes of the West Indian Ocean.

	Baa	Maldives	Laccadives	Chagos	Seychelles	Reunion
Rhodophyta	108	200	71	26	212	122
Chlorophyta	58	97	41	34	102	58
Phaeophyceae	10	24	20	7	54	36
Total species	176	321	132	68	374	215
Shared species		63	45	31	76	52
% Baa		35.7	25.5	17.6	43.1	29.5
Sorensen index (SI)		0.24	0.22	0.2	0.21	0.21

ACKNOWLEDGMENTS

Thanks are expressed to Serge Andréfouët and Shiham Adam who provided us the opportunity to study for the first time the macroalgal flora of Baa. The project was supported by the French Fondation pour la Recherche sur la Biodiversité (FRB) and by the Atoll Ecosystem Conservation project. This work is part of the COREUS team Programme (Institut de Recherche pour le Développement). Laury Dijoux and Nathalie Duong are thanked for their contribution to molecular analysis on *Halimeda* and Dictyotales. Mélanie Hamel is thanked for her contribution to the various maps given in this manuscript. The Marine Research Center of the Maldives is acknowledged for scientific collaboration, and we are especially thankful to Shafiya Naeem and Yoosuf Rilwan from MRC for their logistic and sampling assistance as well as their hospitality and warming company during the field survey. We also thank the Noah team for having made our life onboard easy and enjoyable. Finally, our thanks are addressed to Dr Roy Tsuda for his helpful comments on the manuscript.

REFERENCES

Angiosperm Phylogeny Group III ("APG III": Bremer, B., K. Bremer, M.W. Chase, M.F. Fay, J.L. Reveal, D.E. Soltis, P.S. Soltis, and P.F. Stevens, with collaboration of A.A. Anderberg, M.J. Moore, R.G. Olmstead, P.J. Rudall, K.J. Sytsma, D.C. Tank, K. Wurdack, J.Q.-Y. Xiang, and S. Zmarzty)

2009. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III.*Botanical Journal of the Linnean Society* 161: 105-121.

Aregood, C.C., and H.E. Hackett

1971. A new *Dictyurus* (Rhodophyceae, dasyaceae) from the Maldive Islands, *Indian Oceanic Journal of the Elisha Mitchell Science Society* 87: 91-96.

Barton E.S.

1903. List of marine algae collected at the Maldive and Laccadive Islands by J.S. Gardiner, Esq., M.A. *Journal of the Linnean Society, Botany 35 :* 475-482, pl.

Bellwood, D.R., T.P. Hughes, and A.S. Hoey

2006. Sleeping functional group drives coral-reef recovery. *Current Biology* 16: 2434-2439.

Bouchet, P., P. Lozouet, P. Maestrati, and V. Heros

2002. Assessing the magnitude of species richness in tropical marine environments: exceptionally high numbers of molluscs at a New Caledonia site. *Biological Journal of the Linnean Society* 75: 421−436.

Doty, M. S.

1954. Distribution of the algal genera *Rhipilia* and *Sargassum* in the central Pacific. *Pacific Science* 8: 367-368.

Foslie, M.

1903. The Lithothamnia of the Maldives and Laccadives. Pages 460-471 (Vol. 1) in J.S. Gardiner (ed.). *The fauna and geography of the Maldives and Laccadive archipelagoes. Being the account of the work carried on and of the collections made by an expedition during the years 1899 and 1900*. Cambridge University Press, Cambridge.

Foslie, M

1907. The Lithothamnia. In Gardiner, J.S. 1907-1936. Percy Sladen Trust Expedition to the Indian Ocean in 1905. 1(2) *Transactions of the Linnean Society of London, Second Series,Zoology* 2: 177-192.

Gardiner, J. S.

1903. The fauna and geography o f the Maldive and Laccadive Archipelagoes. Vols. 1-2. Cambridge University Press, Cambridge.

Gepp, A., and E.S. Gepp

1904. *Rhipidosiphon* and *Callipsygma*. *Journal of Botany* 62: 363-366.

Guiry, M.D., and G.M. Guiry

2011. AlgaeBase version 4.2. World-wide electronic publication, National University of Ireland, Galway, http://www.algaebase.org; searched on 15 April 2011.

Hackett, H.E.
1969. Marine algae in the atoll environment: Maldive Islands. *Proceedings of the International Seaweed Symposium* 6: 187-191.
Hackett, H.E.
1977. Marine algae known from the Maldive Islands. *Atoll Research Bulletin*, 210: 1-30, pls. 1& 2.
Hodgson, L. M., and K. J. McDermid.
2000. Marine plants of Pohnpei and Ant Atoll: Chlorophyta, Phaeophyta and Magnoliophyta. *Micronesica* 32: 289-307
Hollenberg, G.J.
1968a. An account of the species of *Polysiphonia* of the central and western tropical Pacific Ocean. I. Oligosiphonia. *Pacific Science* 22: 56-98.
Hollenberg, G.J.
1968b. An account of the species of red algae *Herposiphonia* occurring in the central and western tropical Pacific Ocean. *Pacific Science* 22: 536-559.
McCook, L.J.
1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. *Coral Reefs* 18: 357-367.
Newton, L.M.
1953. Marine Algae. The John Murray Expedition 1933-34 Sci. *Reports* 9(5): 395-420, pls. I-IV. Br. Mus. (Nat. Hist.), London.
Sigee, D.C.
1966. Preliminary account of the land and marine vegetation of Addu Atoll. pp. 61-74. In D. R. Stoddart (ed.), Reef studies at Addu Atoll, Maldive Islands, Preliminary results of an expedition to Addu Atoll in 1964. *Atoll Research Bulletin* 116: 1-122.
Silva, P.C., Basson, P.W. and Moe, R.L.
1996. Catalogue of the benthic marine algae of the Indian Ocean. *University of California Publications in Botany* 79: 1-1259.
Stoddart, D.R. ed.
1966. Reef studies in Addu Atoll, Maldive islands. Preliminary results of an expedition to Addu Atoll in 1964. *Atoll Research Bulletin* 116: 1-122.
Titlyanova, T.V., and P.V. Butorin
1978. Algae of the Maldive and Seychelles Islands. In *Biology of coral reefs: photosynthesis of Zooxanthellae*. Institute of Marine Biology, FarEast Science Centre, Academy of Sciences of the USSR, Vladivostok, Transactions No 12: 19-28.
Tsuda, R. T.
1976. Occurrence of the genus *Sargassum* (Phaeophyta) on two Pacific atolls. *Micronesica* 12: 279-282.
Tsuda, R.T., and J. Newhouse.
1966. Marine benthic algae from Addu Atoll, Maldive Islands. pp. 93–102. In D.R. Stoddart (ed.), Reef studies at Addu Atoll, Maldive Islands,

Preliminary results of an expedition to Addu Atoll in 1964. *Atoll Research Bulletin* 116: 1–122.

Vroom, P. S. K.N. Page, K.A. Peyton and J. K. Kukea-Shultz
2005. Spatial heterogeneity of benthic community assemblages with an emphasis on reef algae at French Frigate Shoals, Northwestern Hawai‘ian Islands. *Coral reefs* 24:574-581 .

Weber Van Bosse, A., and M. Foslie
1904. The Corallinaceae of the Siboga Expedition. Siboga Expeditie 61. E.J. Brill, Leyden.

Weber-van Bosse, A.
1914. The Percy Sladen Trust Expedition to the Indian Ocean in 1905, under the leadership of Mr. J. Stanley Gardiner, M.A. Reports: No. XIV. Marine algae, Rhodophyceae. *Transactions of the Linnean Society of London, Second Series, Zoology* 16: 269-306.

Wynne M.J.
1993. Benthic marine algae from the Maldives, Indian Ocean, collected during the RV Te Vega Expedition. *Contributions of the University of Michigan Herbarium* 19: 5-30, 14.

Appendix 1. Taxonomic list of the macrophytes recorded for Baa Atoll during the present study

Rhodophyta	**Bonnemaisoniales**	**Bonnemaisoniaceae**	*Asparagopsis*	*taxiformis*	(Delile) Trevisan
	Ceramiales	**Callithamniaceae**	*Crouania*	*minutissima*	Yamada
			Seirospora	*orientalis*	G. T. Kraft
		Ceramiaceae	*Centroceras*	*clavulatum*	(C. Agardh) Montagne
			Centroceras	*minutum*	Yamada
			Ceramium	*maryae*	Weber-van Bosse
			Ceramium	*mazatlanense*	E.Y. Dawson
			Corallophila	*apiculata*	(Yamada) R.E. Norris
			Cryptonemia	*umbraticola*	E.Y. Dawson
			Gayliella	*transversalis*	(F.S. Collins et Hervey) T.O. Cho et Fredericq
			Griffithsia	*heteromorpha*	Kützing
		Dasyaceae	*Dasya*	*anastomosans*	(Weber-van Bosse) M.J. Wynne
			Dasya	*baillouviana*	(S. G. Gmelin) Montagne
			Dasya	*palmatifida*	(Weber-van Bosse) A.J.K. Millar et E. Coppejans
			Dictyurus	*purpurascens*	Bory de Saint-Vincent
			Heterosiphonia	*crispella*	(C. Agardh) M.J. Wynne
			Thuretia	sp	
		Delesseriaceae	*Hypoglossum*	*simulans*	M.J. Wynne, Price et Ballantine
			Martensia	*fragilis*	Harvey
			Martensia	*sp. 'petit'*	
			Myriogramme	*heterostroma*	N'Yeurt, M.J. Wynne et Payri
			Myriogramme	*melanesiensis*	N'Yeurt, M.J. Wynne et Payri
			Myriogramme	sp.	
			Nitophyllum	*adhaerens*	M. J. Wynne
		Rhodomelaceae	*Acanthophora*	*pacifica*	(Setchell) Kraft
			Chondria	*arcuata*	Hollenberg
			Chondria	*bullata*	N'Yeurt et Payri
			Chondria	*ryukyuensis*	Yamada
			Chondria	*simpliciuscula*	Weber-van Bosse
			Chondrophycus	*succisus*	(A.B. Cribb) K.W. Nam
			Coelothrix	*irregularis*	(Harvey) Børgesen
			Dipterosiphonia	*dendritica*	(C. Agardh) F. Schmitz

Appendix 1 (Con'td)

			Herposiphonia	*secunda*	(C. Agardh) Ambronn f. *tenella* (C. Agardh) M.J. Wynne
Rhodophyta	**Ceramiales**	**Rhodomelaceae**	*Laurencia*	*cf minuta*	Vandermeulen, Garbary et Guiry
			Laurencia	*distichophylla*	J. Agardh
			Laurencia	sp. 1	
			Laurencia	sp. 2	
			Laurencia	sp. 3	
			Laurencia	sp. 4	
			Laurencia	sp. 5	
			Leveillea	*jungermannioides*	(K. Hering et G. Martens) Harvey
			Neosiphonia	*apiculata*	(Hollenberg) Masuda et Kogame
			Neosiphonia	*ferulacea*	(Suhr ex J. Agardh) S.M. Guimarães et M.T. Fujii
			Palisada	*parvipapillata*	(C. K. Tseng) K. W. Nam
			Polysiphonia	*delicatula*	Hollenberg
			Polysiphonia	*sertularioides*	(Grateloup) J. Agardh
			Tolypiocladia	*glomerulata*	(C. Agardh) F. Schmitz
		Wrangeliaceae	*Wrangelia*	*sp. inedit*	
	Corallinales	**Corallinaceae**	*Amphiroa*	*foliacea*	Lamouroux in Quoy et Gaimard
			Amphiroa	*fragilissima*	(Linnaeus) Lamouroux
			Amphiroa	*rigida*	J.V. Lamouroux
			Amphiroa	*tribulus*	(Ellis et Solander) Lamouroux
			Amphiroa	sp	
			Hydrolithon	*gardneri*	(Foslie) Verheij & Prud'homme van Reine
			Hydrolithon	*onkodes*	(Heydrich) D. Penrose et Woelkerling
			Hydrolithon	*reinboldii*	(Weber-van Bosse et Foslie) Foslie
			Hydrolithon	sp	
			Jania	*adhaerens*	Lamouroux
			Lithophyllum	*bamleri*	(Heydrich) Heydrich
			Lithophyllum	*kotschyanum*	Unger
			Lithothamnion	*proliferum*	Foslie
			Lithothamnion	sp	
			Mesophyllum	*erubescens*	(Foslie) M. Lemoine
			Mesophyllum	sp	
			Neogoniolithon	*brassica-florida*	(Harvey) Setchell et L.R. Mason
			Neogoniolithon	*frutescens*	(Foslie) Setchell & L.R.Mason

Appendix 1 (Con’td)

			Neogoniolithon	*laccadivicum*	(Foslie) Setchell & Mason
Rhodophyta	**Gelidiales**	**Gelidiaceae**	*Caulacanthus*	*ustulatus*	(Turner) Kützing
			Gelidium	*isabelae*	W.R. Taylor
			Gelidium	sp	
			Pterocladiella	*caespitosa*	(Kylin) Santelices
			Pterocladiella	*caloglossoides*	(M.A. Howe) Santelices
		Gelidiellaceae	*Gelidiella*	*acerosa*	(Forsskål) Feldmann et G. Hamel
			Gelidiella	*myrioclada*	(Børgesen) Feldmann et G. Hamel
	Gigartinales	**Corynocystaceae**	*Corynocystis*	*prostrata*	G.T. Kraft
		Dumontiaceae	*Gibsmithia*	*dotyi*	Kraft et Ricker
			Gibsmithia	*hawaiiensis*	Doty
		Hypneaceae	*Hypnea*	*nidulans*	Setchell
			Hypnea	*pannosa*	J. Agardh
			Hypnea	*spinella*	(C. Agardh) Kützing
		Kallymeniaceae	*Kallymenia*	*thompsonii*	Abbott et McDermid
		Peyssonneliaceaea	*Peyssonnelia*	cf. *boergesenii*	Weber-van Bosse
			Peyssonnelia	*inamoena*	Pilger
		Rhizophyllidaceae	*Portieria*	*hornemannii*	(Lyngbye) P.C. Silva
	Halymeniales	**Halymeniaceae**	*Halymenia*	*actinophysa*	M. A. Howe
			Halymenia	*durvillei*	Bory de Saint-Vincent
			Halymenia	*maculata*	J. Agardh
	Nemaliales	**Galaxauraceae**	*Actinotrichia*	*fragilis*	(Forsskål) Børgesen
			Actinotrichia	sp	
			Galaxaura	*filamentosa*	R. Chou
	Rhodymeniales	**Champiaceae**	*Champia*	*compressa*	Harvey
			Champia	*parvula*	(C. Agardh) Harvey
			Coelothrix	*irregularis*	(Harvey) Børgesen
		Faucheaceae	*Gloiocladia*	*iyoensis*	(Okamura) R. Norris
		Leptofaucheaceae	*Leptofauchea*	sp	
		Rhodymeniaceae	*Asteromenia*	*anastomosans*	(Weber-van Bosse) G. W. Saunders, C. E. Lane, C. W. Schneider et Kraft
			Botryocladia	*skottsbergii*	(Børgesen) Levring
			Botryocladia	*tenuissima*	W.R. Taylor

Appendix 1 (Con'td)

Rhodophyta	**Rhodymeniales**	**Rhodymeniaceae**	*Chamaebotrys*	*boergesenii*	(Weber-van Bosse) Huisman
			Gelidiopsis	*intricata*	(C. Agardh) Vickers
			Halichrysis	*irregularis*	Kützing
			Lomentaria	*corallicola*	Børgesen
			Rhodymenia	sp.1	
			Rhodymenia	sp.2	
			Rhodymenia	sp.4	
			Rhodymenia	sp.5	
			Spirocladia	*barodensis*	Børgesen
	Sporolithales	**Sporolithaceae**	*Sporolithon*	*ptychoides*	Heydrich
Chlorophyta	**Bryopsidales**	**Bryopsidaceae**	*Bryopsis*	*pennata*	J.V. Lamouroux
			Bryopsis	*plumosa*	(Hudson) C. Agardh
			Bryopsis	sp	
		Caulerpaceae	*Caulerpa*	*cupressoides*	(Vahl) C. Agardh
			Caulerpa	*diligulata*	G.T. Kraft et A.J.K. Millar
			Caulerpa	*filicoides*	Yamada
			Caulerpa	*nummularia*	Harvey ex J. Agardh
			Caulerpa	*racemosa*	(Forsskål) J. Agardh var. *peltata* (Lamouroux) Eubank
			Caulerpa	*sedoides*	C. Agardh
			Caulerpa	*serrulata*	(Forsskål) J. Agardh
			Caulerpa	*sertularioides*	(S. Gmelin) M. Howe
			Caulerpa	*taxifolia*	(Vahl) C. Agardh
			Caulerpa	*tongaensis*	Papenfuss
		Codiaceae	*Codium*	*arabicum*	Kützing
			Codium	*geppiorum*	O.C. Schmidt
		Halimedaceae	*Halimeda*	*cuneata*	Hering
			Halimeda	*discoidea*	Decaisne
Chlorophyta	**Bryopsidales**	**Halimedaceae**	*Halimeda*	*distorta*	(Yamada) Hillis-Colinvaux
			Halimeda	*fragilis*	W.R. Taylor
			Halimeda	*gracilis*	Harvey ex J. Agardh
			Halimeda	*micronesica*	Yamada
			Halimeda	*minima*	(W.R. Taylor) Colinvaux
			Halimeda	*opuntia*	(Linnaeus) Lamouroux
			Halimeda	*taenicola*	W.R. Taylor

Appendix 1 (Con’td)

Chlorophyta	**Bryopsidales**	**Halimedaceae**	*Halimeda*	*velasquezii*	W.R. Taylor
			Halimeda	*xishaensis*	M.L.Dong & C.K.Tseng
			Halimeda	sp	
		Udoteaceae	*Avrainvillea*	*lacerata*	Harvey ex J. Agardh
			Boodleopsis	*pusilla*	(F.S. Collins) W.R. Taylor, A.B. Joly et Bernatowicz
			Boodleopsis	sp.	
			Chlorodesmis	*fastigiata*	(C. Agardh) Ducker
			Chlorodesmis	*hildebrandtii*	A. Gepp et E.S. Gepp
			Rhipidosiphon	*javensis*	Montagne
			Rhipilia	*crassa*	A.J.K. Millar et Kraft
			Rhipiliella	*verticillata*	G.T. Kraft
			Rhipiliopsis	*gracilis*	Kraft
			Tydemania	*expeditionis*	Weber-van Bosse
Chlorophyta	**Cladophorales**	**Anadyomenaceae**	*Anadyomene*	*wrightii*	Harvey ex J. Gray
			Cladophora	*dotyana*	Gilbert
			Cladophora	*feredayoides*	Kraft et Millar
			Cladophora	*goweri*	A.H.S. Lucas
			Cladophora	*prehendens*	Kraft et Millar
			Cladophora	*rupestris*	(Linnaeus) Kützing
			Cladophora	*vagabunda*	(Linnaeus) Hoek
			Cladophora	sp.	
			Microdictyon	*okamurae*	Setchell
		Siphonocladacaeae	*Boergesenia*	*forbesii*	(Harvey) J. Feldmann
			Boodlea	*composita*	(Harvey) F. Brand
			Cladophoropsis	*herpestica*	(Montagne) M.A. Howe
			Cladophoropsis	*vaucheriaeformis*	(J.E Areschoug) Papenfuss
			Dictyosphaeria	*cavernosa*	(Forsskål) Børgesen
			Dictyosphaeria	*versluysii*	Weber-van Bosse
			Phyllodictyon	*anastomosans*	(Harvey) Kraft et M.J. Wynne
		Valoniaceae	*Valonia*	*aegagropila*	C. Agardh
			Valonia	*fastigiata*	Harvey ex J. Agardh
			Valonia	*ventricosa*	J. Agardh
			Valoniopsis	*pachynema*	(G. Martens) Børgesen
Chlorophyta	**Dasycladales**	**Dasycladaceae**	*Neomeris*	*annulata*	Dickie

Appendix 1 (Con’td)

		Polyphysaceae	*Parvocaulis*	*parvulus*	(Solms-Laubach) S. Berger et al.
	Ulvales	**Ulvaceae**	*Ulva*	*flexuosa*	(Wulfen) J. Agardh
Phaeophyceae	**Dictyotales**	**Dictyotaceae**	*Dictyopteris*	*repens*	(Okamura) Børgesen
			Dictyota	*bartayresiana*	Lamouroux
Phaeophyceae	**Dictyotales**	**Dictyotaceae**	*Dictyota*	*ceylanica*	Kützing
			Dictyota	*friabilis*	Setchell
			Dictyota	*grossedentata*	De Clerck et Coppejans
			Dictyota	*humifusa*	Hörnig, Schnetter et Coppejans
			Dictyota	sp.1	
			Lobophora	*variegata*	(Lamouroux) Womersley ex Oliveira
			Padina	*okinawaensis*	Ni-NI-Win, S. Arai & H. Kawai
	Fucales	**Sargassaceae**	*Turbinaria*	*ornata*	(Turner) J. Agardh
Magnolophyta	**Alimastales**	**Cymodoceacea**	*Syringodium*	*isoetifolium*	(Ascherson) Dandy
		Hydrocharitaceae	*Thalassia*	*hemprichii*	(Ehrenberg) Ascherson

Appendix 2. Presence /absence of macroalgal species at prospected sites in Baa Atoll

Genus	species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	27	28
Anadyomene	*wrightii*			1					1				1			1		1	1			1			1			
Avrainvillea	*lacerata*											1			1					1		1	1			1		1
Boergesenia	*forbesii*				1																							1
Boodlea	*composita*								1	1		1		1			1		1	1		1						1
Boodleopsis	*pusilla*																			1								
Boodleopsis	sp.			1																								
Bryopsis	*pennata*			1	1			1	1		1	1	1		1		1			1		1	1		1	1		
Bryopsis	*plumosa*												1															
Bryopsis	sp.											1														1		1
Caulerpa	*cupressoides*									1																		
Caulerpa	*diligulata*	1			1			1			1	1			1			1	1	1							1	
Caulerpa	*filicoides*														1													
Caulerpa	*nummularia*						1																		1	1		
Caulerpa	*racemosa*																									1		1
Caulerpa	*sedoides*																		1									
Caulerpa	*serrulata*					1				1								1	1									
Caulerpa	*sertularioides*						1																					
Caulerpa	*taxifolia*								1								1	1										
Caulerpa	*tongaensis*										1																	
Chlorodesmis	*fastigiata*											1						1	1	1								
Chlorodesmis	*hildebrandtii*	1							1																		1	
Cladophora	*dotyana*																	1	1									
Cladophora	*feredayoides*	1			1			1			1				1				1									
Cladophora	*goweri*									1																		
Cladophora	*prehendens*																1						1					
Cladophora	*rupestris*	1																										
Cladophora	*vagabunda*																								1			
Cladophora	sp.				1																							
Cladophoropsis	*herpestica*										1							1										
Cladophoropsis	*vaucheriaeformis*	1			1			1			1	1			1	1			1	1							1	
Codium	*arabicum*																											1

Appendix 2 (Con'td)

Genus	species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	27	28
Codium	*geppiorum*	1							1				1															
Dictyosphaeria	*cavernosa*																									1		
Dictyosphaeria	*versluysii*								1																			
Halimeda	*cuneata*	1		1		1	1								1			1	1	1		1	1		1	1	1	1
Halimeda	*distorta*	1				1	1	1				1			1					1				1			1	
Halimeda	*gracilis*	1				1	1	1				1					1	1	1			1			1	1		1
Halimeda	*micronesica*																			1	1							
Halimeda	*minima*			1		1	1	1	1		1	1	1		1		1	1	1	1		1	1		1	1	1	1
Halimeda	*opuntia*	1	1				1		1	1	1	1	1	1	1	1			1	1	1					1		1
Halimeda	*taenicola*																			1	1							
Halimeda	*velasquezii*														1													
Halimeda	*xishaensis*							1							1												1	
Halimeda	sp.					1																						
Microdictyon	*okamurae*														1													
Neomeris	*annulata*								1	1																		
Parvocaulis	*parvulus*													1														
Phyllodictyon	*anastomosans*			1				1				1			1				1			1			1		1	
Rhipidosiphon	*javensis*			1	1	1	1						1		1			1	1	1			1		1	1		1
Rhipilia	*crassa*														1													1
Rhipiliella	*verticillata*			1									1					1							1			
Rhipiliopsis	*gracilis*																					1						
Tydemania	*expeditionis*	1		1	1		1	1			1	1	1		1	1		1	1	1	1	1	1		1	1	1	1
Ulva	*flexuosa*													1									1					
Valonia	*aegagropila*		1																									
Valonia	*fastigiata*				1										1													
Valonia	*ventricosa*	1		1		1									1								1		1			
Valoniopsis	*pachynema*																					1						
Dictyopteris	*repens*			1									1			1						1				1		
Dictyota	*bartayresiana*						1	1																				
Dictyota	*ceylanica*									1																		
Dictyota	*friabilis*	1					1	1	1		1	1						1	1	1		1			1	1		
Dictyota	*grossedentata*											1																
Dictyota	*humifusa*							1			1	1							1									1
Dictyota	sp.1			1																								
Lobophora	*variegata*	1		1		1	1	1			1	1	1						1			1			1			
Padina	*okinawaensis*									1						1			1									

Appendix 2 (Con'td)

Genus	**species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**27**	**28**
Turbinaria	*ornata*					1	1																					
Acanthophora	*pacifica*						1	1			1	1			1		1										1	
Actinotrichia	*fragilis*			1		1						1	1															1
Actinotrichia	sp.	1		1			1	1				1																
Amphiroa	*foliacea*			1																								
Amphiroa	*fragilissima*														1													
Amphiroa	*rigida*			1																								
Amphiroa	*tribulus*			1																								
Amphiroa	*sp.*										1																	
Asparagopsis	*taxiformis*								1							1												
Asteromenia	*anastomosans*				1			1							1												1	
Botryocladia	*skottsbergii*						1					1				1						1					1	1
Botryocladia	*tenuissima*			1																								
Caulacanthus	*ustulatus*												1															1
Centroceras	*clavulatum*													1														
Centroceras	*minutum*									1																		
Ceramium	*maryae*			1		1					1	1					1											
Ceramium	*mazatlanense*																1											
Chamaebotrys	*boergesenii*	1						1					1														1	
Champia	*compressa*			1	1		1	1				1						1					1		1	1		1
Champia	*parvula*									1																1		
Chondria	*arcuata*																			1								
Chondria	*bullata*														1													
Chondria	*ryukyuensis*										1									1								
Chondria	*simpliciuscula*			1						1																		
Chondrophycus	*succisus*											1																
Coelothrix	*irregularis*																											1
Corallophila	*apiculata*						1																					
Corynocystis	*prostrata*					1													1			1						
Crouania	*minutissima*																1											
Cryptonemia	*umbraticola*	1				1									1			1	1									
Dasya	*anastomosans*							1														1						
Dasya	*baillouviana*														1				1									
Dasya	*palmatifida*								1																			
Dictyurus	*purpurascens*			1					1													1						1
Dipterosiphonia	*dendritica*							1																				

Appendix 2 (Con'td)

Genus	species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	27	28
Leveillea	*jungermannioides*											1		1		1												
Lithophyllum	*bamleri*	1																										
Lithophyllum	*kotschyanum*	1		1		1	1										1					1	1		1	1		1
Lithothamnion	*proliferum*	1			1	1		1			1	1			1				1			1	1		1	1	1	1
Lithothamnion	sp				1	1					1				1				1			1	1		1	1	1	
Lomentaria	*corallicola*											1																
Martensia	*fragilis*																			1							1	
Martensia	sp																		1							1		
Mesophyllum	*erubescens*										1	1																
Mesophyllum	sp				1																	1						
Myriogramme	*heterostroma*							1														1			1			
Myriogramme	*melanesiensis*														1													
Myriogramme	sp																					1			1			
Neogoniolithon	*brassica-florida*									1				1								1	1					
Neogoniolithon	*frutescens*	1	1											1								1	1					
Neogoniolithon	*laccadivicum*		1																				1					
Neosiphonia	*apiculata*																			1								
Neosiphonia	*ferulacea*																		1									
Nitophyllum	*adhaerens*			1																								
Palisada	*parvipapillata*								1																			
Peyssonnelia	*cf. boergesenii*																								1			
Peyssonnelia	*inamoena*														1								1					
Polysiphonia	*delicatula*				1							1																
Polysiphonia	*sertularioides*						1																1					
Portieria	*hornemannii*								1																			
Pterocladiella	*caespitosa*																										1	
Pterocladiella	*caloglossoides*					1																						
Rhodymenia	sp.1										1	1																
Rhodymenia	sp.2																							1				
Rhodymenia	sp.3																										1	
Rhodymenia	sp.4																											1
Seirospora	*orientalis*																	1										
Spirocladia	*barodensis*											1							1									
Sporolithon	*ptychoides*				1	1	1	1				1			1				1						1			1
Thuretia	sp.			1	1																							
Tolypiocladia	*glomerulata*							1		1				1									1					

Appendix 2 (Con’td)

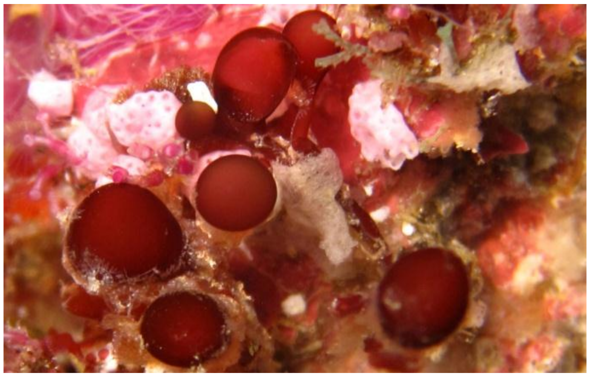
Genus	**species**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**27**	**28**
Wrangelia	*sp. inedit*															1										1		
Syringodium	*isoetifolium*		1																									
Thalassia	*hemprichii*		1																									

Appendix 3

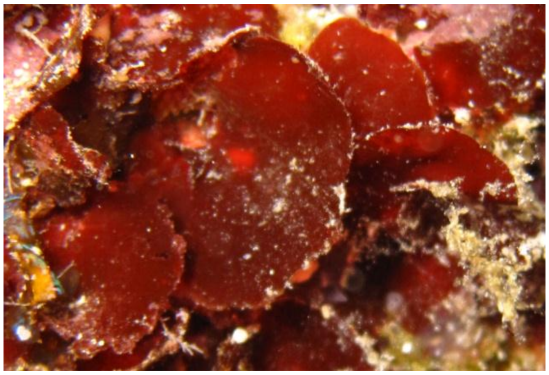
Rhodophyta 1/4

Gibsmithia hawaiensis

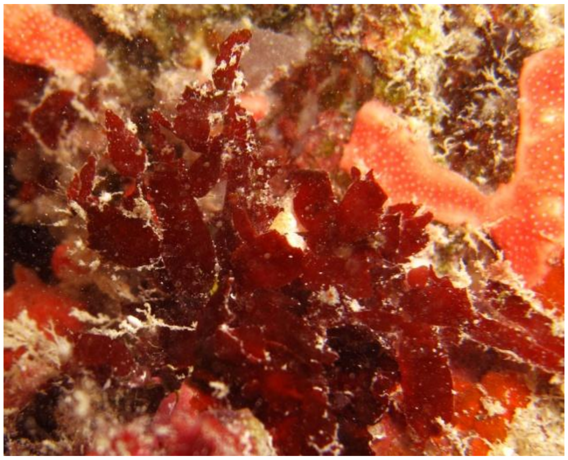
Gibsmithia dotyii



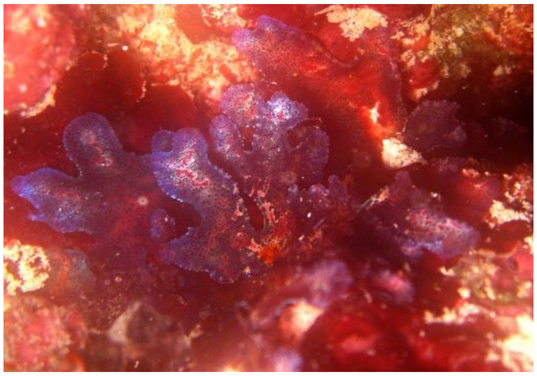
Botryocladia skottsbergii



Cryptonemia umbraticola



Corynocystis prostrata



Asteromenia anastomosans

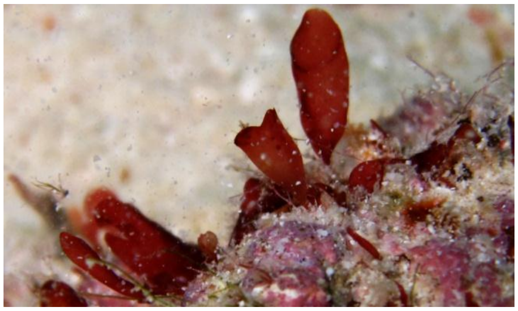
Rhodophyta 2/4

 *Actinotrichia* sp	 *Actinotrichia fragilis*
 *Acanthophora pacifica*	 *Amphiroa tribulus*
 *Dictyurus purpurascens*	 *Kallymenia thompsonii*

Rhodophyta 3/4

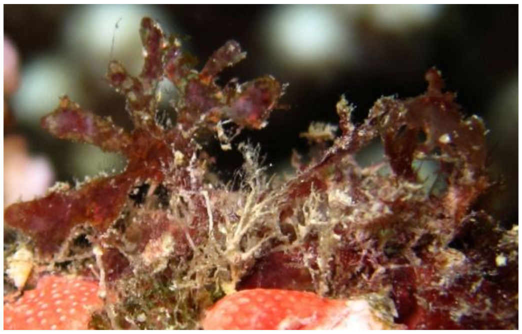

Halymenia durvillei


Coelothrix irregularis

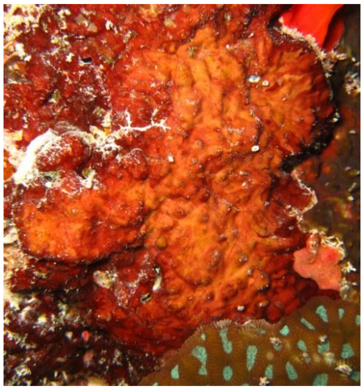

Gelidium isabelae


Heterosiphonia crispella

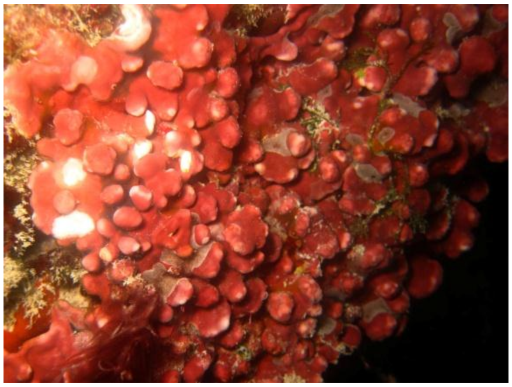
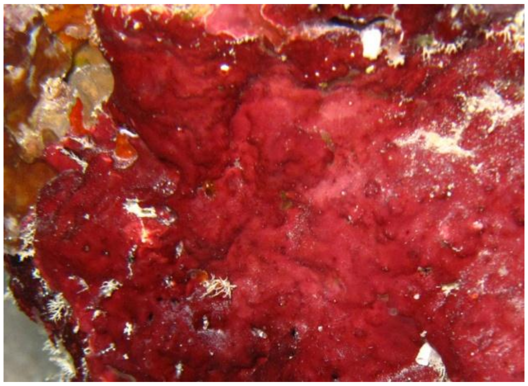

Martensia fragilis


Myriogramme heterostroma


Myriogramme sp.

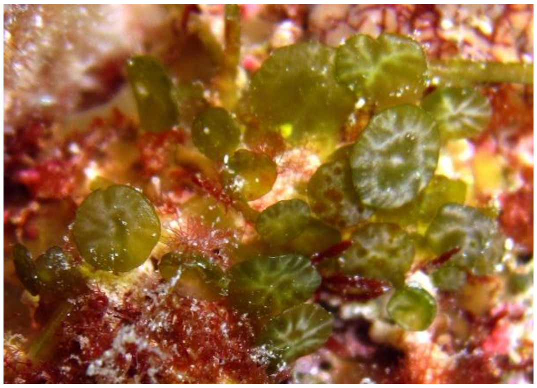

Peyssonnelia sp.

Rhodophyta 3/4

 *Hydrolithon gardneri*	 *Lithothamnion proliferum*
 *Hydrolithon* sp1	 *Sporolithon ptychoides.*

Chlorophyta 1/4

Caulerpa serrulata



Caulerpa racemosa var. peltata

Caulerpa diligulata

Tydemania expeditionis

Avrainvillea lacerata

Rhipidosiphon javensis

Chlorophyta 2/4

Halimeda cuneata

Halimeda distorta

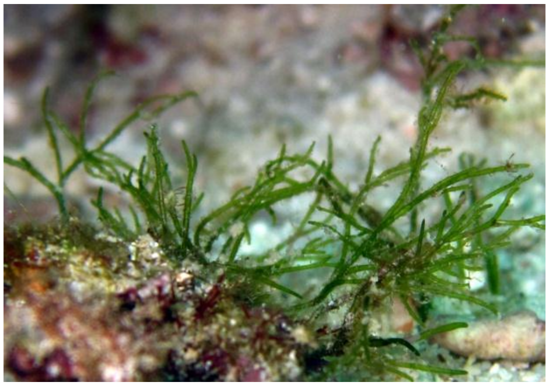
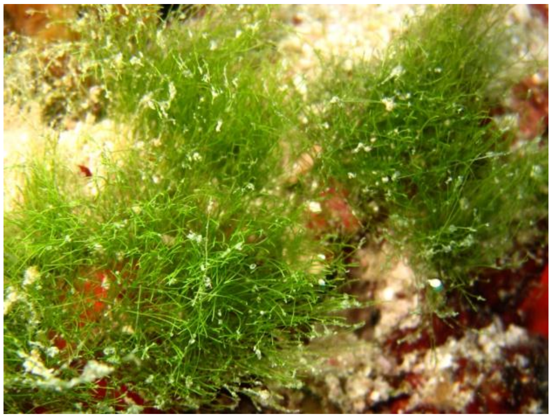
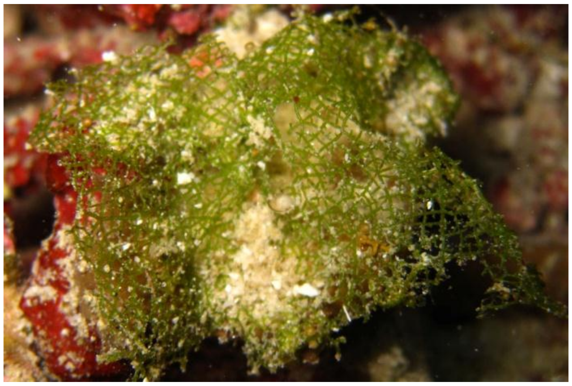
Halimeda gracilis

Halimeda micronesica

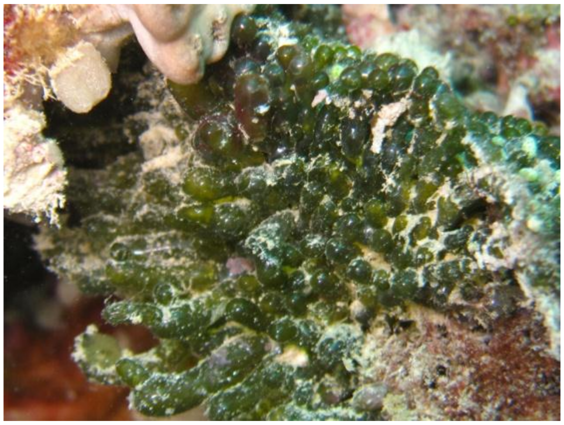
Halimeda minima

Halimeda opuntia

Chlorophyta 3/4

 *Bryopsis pennata*	 *Cladophoropsis vaucheriaeformis*
 *Chlorodesmis fastigiata*	 *Phyllodictyon anastomosans*
 *Cladophora feredayoides*	 *Microdictyon umbilicatum*

Chlorophyta 4/4



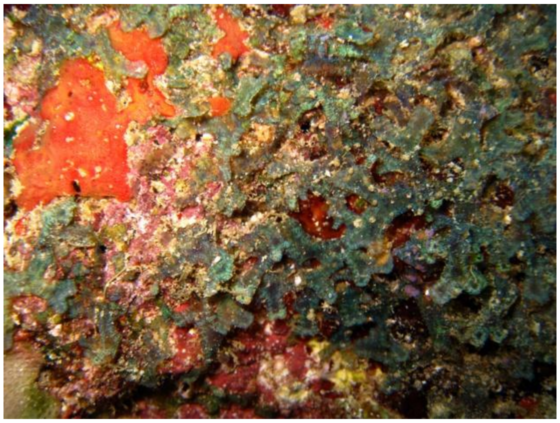
Valonia fastigiata

Valonia ventricosa

Boergesenia forbersii

Boodleopsis pusilla

Phaeophyceae 1/1

 *Lobophora variegata*	 *Padina okinawensis*
 *Dictyota friabilis*	 *Dictyota humifusa*

Magnolophyta 1/1

 *Cymodocea serrulata*	 *Syringodium isoetifolium*

SCLERACTINIA CORALS OF BAA ATOLL (MALDIVES): FIRST CHECKLIST AND OVERVIEW OF STONY CORALS COMMUNITY STRUCTURE

BY

LIONEL BIGOT[1] AND HANI AMIR[2]

ABSTRACT

A survey of scleractinian corals for 21 stations in Baa Atoll (Republic of Maldives) was conducted in June 2009. The goal of the survey was to i) compile for the first time for this atoll a scleractinian coral check-list, ii) estimate the atoll total richness, iii) estimate intra-atoll richness variation and iv) describe preliminary patterns of community structure according to geomorphology and location criteria. The survey was stratified by the main reef geomorphological units. A total of 173 species of scleractinia belonging to 49 genera were recorded, including several species new to Maldives. Conversely, a number of species of genera quite common in the Indian Ocean were absent of the list of Pocilloporidae. Average richness per station was nearly 60 species. Richness ratio between slopes and flats/tops were between 3 and 1.3, with an average of 2.1, highlighting richer slopes than flats and tops. Differences of community composition between geomorphologic strata and between oceanic/lagoonal reefs were significant. Central lagoonal reefs provided highest richness, and highest coral cover as well. These findings are critical to plan for the conservation of Baa Atoll biodiversity.

INTRODUCTION

Historically, the Pillai and Scheer (1976) study provided the first Maldivian checklist of stony corals, from samples collected in 1957 and 1958 during the "Xarifa expedition" (Wallace and Zahir, 2007). The second significant contribution was the coral list proposed by Sheppard (1987) as a compilation of scleractinian species for various areas of Indian Ocean, including coral fauna of the Maldives. Finally, the most recent taxonomic census has been realized by Pichon and Benzoni (2007), based on 2002 /2003 field observations, after the 1998 regional bleaching event that seriously impacted coral communities of Maldives (Zahir et al. 2006; Lasagna et al. 2010, McClanahan, 2000). Pichon and Benzoni (2007) sampled 34 stations in Ari (Alifu), South Male (Kaafu),Vattaru and Felidhoo (Vaavu) Atolls. Additional data were added by numerous authors on limited number of sites (reviewed in Pichon and Benzoni, 2007). Despite this knowledge, taxonomic inventories of stony corals remain scarce for the entire

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archipelago, and are often limited to specific atolls. Furthermore, additional collections remain partly unprocessed due to the taxonomic revision of a specific group (*Acropora* collection by Wallace, 1999).

Specifically for Baa Atoll, the taxonomic composition of scleractinian coral communities remains poorly known. The Atoll Ecosystem Conservation Project (http://www.biodiversity.mv/aec/) has funded in 2008 a Baa-wide rapid assessment of coral communities (Le Berre et al., 2009), but manta tow surveys provided dominant growth forms and coral cover, not taxonomic lists. By providing a first qualitative description of hard coral communities and their main taxonomic dominance, across Baa Atoll coral habitats, this study fills a significant gap in Baa biodiversity knowledge.

MATERIAL AND METHODS

Scleractinian communities were described in June 2009 for 21 sites and 30 sampling stations across Baa Atoll (Fig. 1). The 21 sites included lagoon and oceanic sites (Fig. 1). The 30 sampling stations comprised four main coral reef habitats. Namely, these are reef slopes (5-20 meters), reef flats (0-2 meters), reef tops (the reef escarpment generally between 2 and 5 meters), and patch reefs (submerged isolated small reefs, below 10 meters of water). Thus, a site included 1 or 2 stations at most, since the upper part of a reef site was either a reef flat or a reef top.

For each site, scleractinia were sampled and/or recorded by SCUBA during a search time of 1 hour per station following a random path, going from the deeper areas to the shallowest. Slope, reef tops and reef flat station records were kept separate if done during the same dive. Forereef sampling was limited to the upper bio-constructed zones (approximately 5-20 meters). Generally, below 20 meters, sedimentary areas became dominant and corals scarce. Deep environments were mainly made of detritical coral reef habitats, sands and rubble.

The species were identified to the lowest tractable taxonomic level (species) excepted for the *Acropora* communities (species or genus level). Most species and all samples were photographed in situ. *Acropora* (21 samples) and Faviidae (5 samples) specimen have been collected for subsequent examination and deposited in Museum National in St Denis, La Reunion, and Muséum National Histoire Naturelle in Paris). Their taxonomic identification is in progress and results will be reported elsewhere.

Most dominant / abundant species have been recorded during the survey using a semi-quantitative scale (- scarse, singleton ; + average dominance ; ++ high dominance ; +++ very high dominance).

For each site and for each station (or habitat), a list of species was compiled. The coral species nomenclature used in this paper follows recent taxonomic revisions and monographs (Pichon and Benzoni, 2007). From the lists, univariate statistics provided richness indices per site and per station, (number of species and number of families) in order to assess trends in coral communities patterns per site (oceanic/lagoon) and per habitat (reef slope, reef top, reef flat, patch reef).

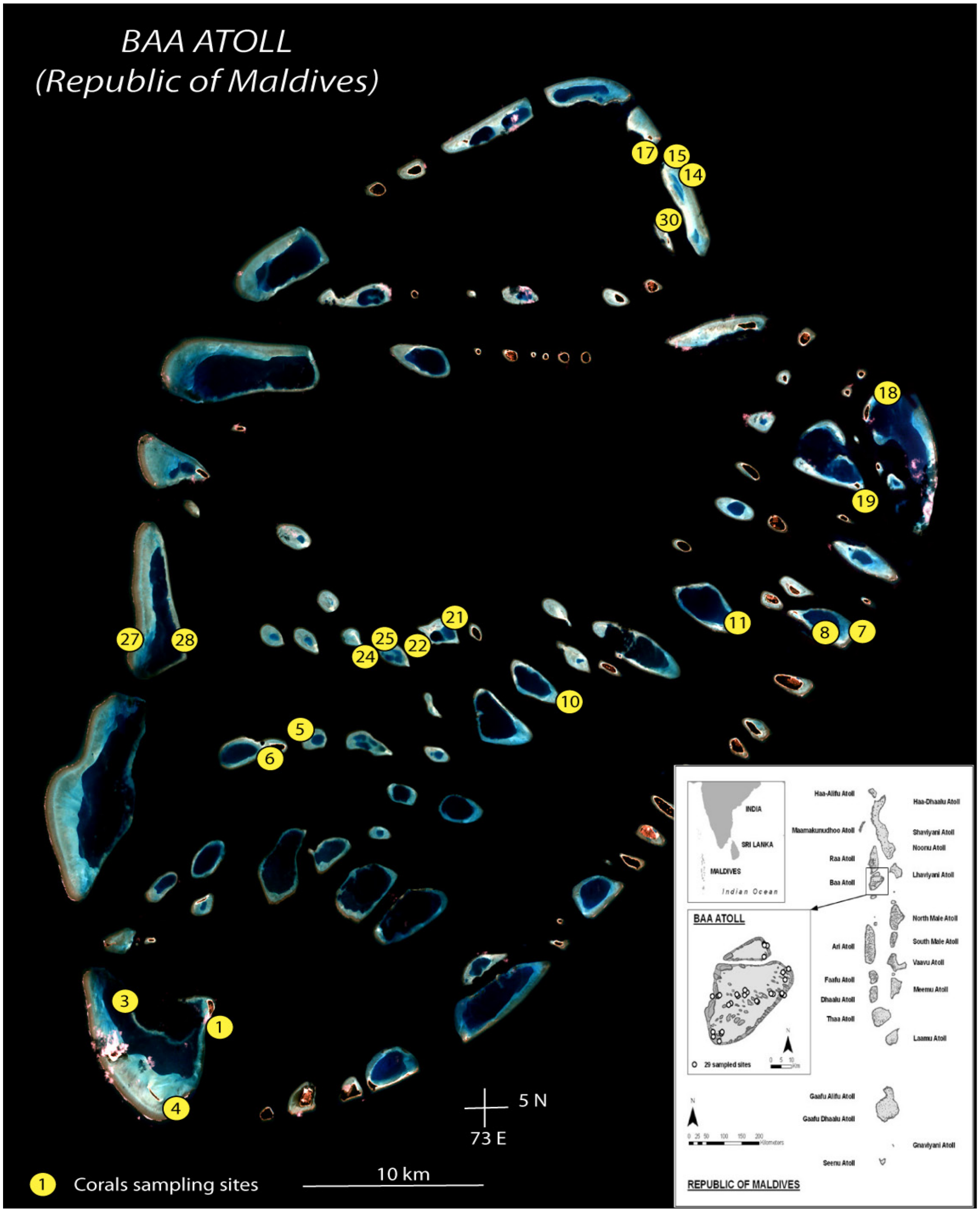


Figure 1. Map of Baa Atoll and position of the 21 coral reef sampling sites visited in June 2009.

Multivariate analysis (nMDS and ANOSIM) were performed on qualitative (presence & absence) data set only using the PRIMER 6 software (Clarke and Goorley, 2006). Bray-Curtis similarities were computed between each pair of stations. Non-metric multidimensional scaling (nMDS) displayed the different sources of variation in coral community structure, according to differences between sites (geography-exposure such as central lagoon and atoll rim periphery) and habitats. Results were tested using ANOSIM permutation tests (Clarke & Warwick, 2001).

RESULTS AND DISCUSSION

Overall Coral Species Richness

A total of 177 species of Scleractinia belonging to 49 genera were recorded in Baa Atoll. The list is presented in alphabetical order for the families, genera and species (appendix, Table 1). Acroporidae and Faviidae represented 55 and 46 species respectively (31% and 26 % of the coral community) (Fig. 2). Agaricidae and Fungiidae represented 14 % of the assemblage, other families were only represented by few species (1 to 4 %). Examples of specimen and facies are photographed in Plates 1 to 3.

Species richness reported here for Baa Atoll is consistent with scleractinian richness reported in other Maldives areas. For instance, Pichon and Benzoni (2007) reported 180 species from 4 atolls, identified on lagoon and oceanic reef slopes from the top down to 50 meters. The same authors reported a total of 258 species and 57 genera from a compilation of published sources.

By comparison with the list from Pichon and Benzoni (2007), we report that several species present in Baa Atoll were recorded for the first time in Maldives (*Montastrea magnistellata*, *Barabattoia cf. laddi*, *Turbinaria reniformis*, *Leptastrea pruinosa*). Previously, their presence could only be assumed according to distribution maps given by Veron (2000). Some of these newly recorded species were found relatively abundant in their preferred type of habitat (e.g., *Montastrea magnistellata*, L*eptastrea puinosa*, *Platygyra pini*, *Goniopora stutchburyi*) in agreement with similar observations made by Pichon and Benzoni (2007) for several species new to Maldives that they identified on their sampling sites.

For many sites located in the central part of Baa Atoll, *Acropora* communities were spectacular and charcacterized by tabular *Acropora* assemblages (*Acropora hyacinthus*, *A. cytherea*, *A. divaricata*), “bottlebrush” assemblages (*Acropora elseyi*, *A. longicyathus*), and branching or digitate assemblages (*Acropora muricata* “group”, *A. austera*, *A. samoensis*, *A. humilis*, *A digitifera*) (Wallace, 1999) (Appendix). Faviidae were also very common and often characterized by the presence of genera *Favia* and *Montastrea* (*M. annuligera*, *M. valenciennesi*, *M. magnistellata*). Agaricidae communities were dominated by *Leptoseris* (*Leptoseris scabra*, *L. hawaiensis*) and *Pavona* (*P. explanulata*, *P. venosa*, *P. varians*, *P. maldiviensis*).

Surprisingly, a number of species quite common in the Indian Ocean were absent from the list of Pocilloporidae (*Seriatopora histryx*, *S. caliendrum* or *Stylophora pistillata*). Similar observation was made for Milleporidae and other various species of hydrozoans during the same 2009 campaign (Gravier-Bonnet and Bourmaud, this issue).

As it stands now, the list published here is obviously conservative and incomplete. Indeed, *Acropora* samples need to be investigated to establish final conclusions on the alpha diversity of Baa Atoll. Furthermore, the major collection effort had taken place in the most dominant reef habitats of Baa Atoll. Many other habitats and niches still need to be sampled, including the deeper environments found in the lagoon, passes and oceanic fore reefs. Likely, the exploration of these habitats could yield additional species.

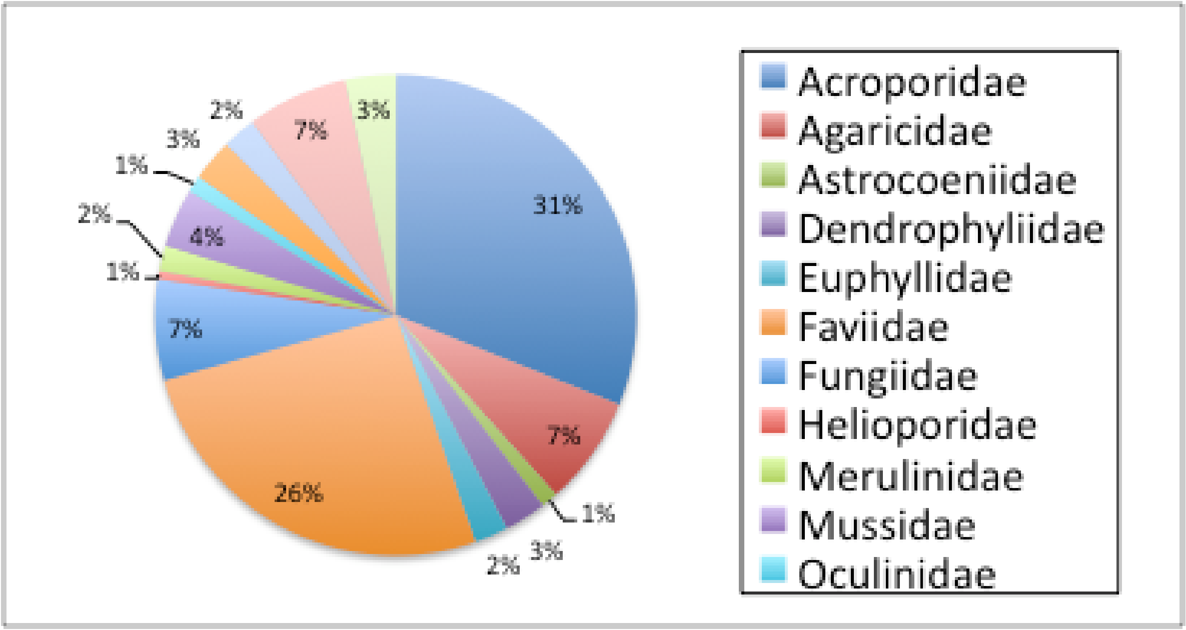


Figure 2. Proportion of coral reef families found in Baa Atoll (June 2009) considering all the sites.

Variations in Coral Community Structures

At the scale of the station, the average richness was just under 60 species, with a maximum at 74 and a minimum at 21. For the sites sampled both on reef slopes and reef flats/tops (n=8, ocean and lagoon sites), richness ratio between slopes and flats/tops were between 3 and 1.3, with an average of 2.1. Slopes were thus much richer than reef tops and flats. Richness on oceanic reef slopes (63.7 ± 6.9; n=8) were not significantly different than lagoon reef slopes (57.0 ± 9.5; n=4).

The highest coral richness recorded during this survey (often higher than 70 species) were also frequently associated with high coral cover (up to 80 %) (Le Berre et al., 2009). However, this is true only for lagoon stations. The health of these sites in terms of cover and richness are exceptional per Indian Ocean standards (plates 1, 2, 3) (Rajasuriya et al., 2002; Sheppard et al., 2008, Zahir et al, 2006).

The variations of facies observed in Baa is consistent with the categorisation of coral communities provided by Lasagna et al. (2010a). Based on the relative proportion of live coral and loose sediments and the three dimensional structure of the communities, they identified young, mature and regressive communities both on reef flats and slopes from Central Maldives atolls. Flats, especially in the central faro reefs where wave energy is low, appeared in Baa in young stage, whereas more exposed flats and slopes were of the mature and regressive forms. However, the classification by Lasagna et al; (2010a) would need to be tuned considering separately the communities dominated by *Acropora* (as in Lasagna et al., 2010b) and those dominated by massive *Porites*, which visually dominate the reefscape in the north eastern outer reefs of Baa (Le Berre et al., 2009).

The variation of richness per type of habitat sampled in Baa is presented for the 30 sampled stations in Figure 3. Baa sampling confirm the higher level of diversity founded in the central faro reefs slopes of Baa Atoll (stations 21, 22, 24, 25) and in central patch reefs (stations 11, 5).

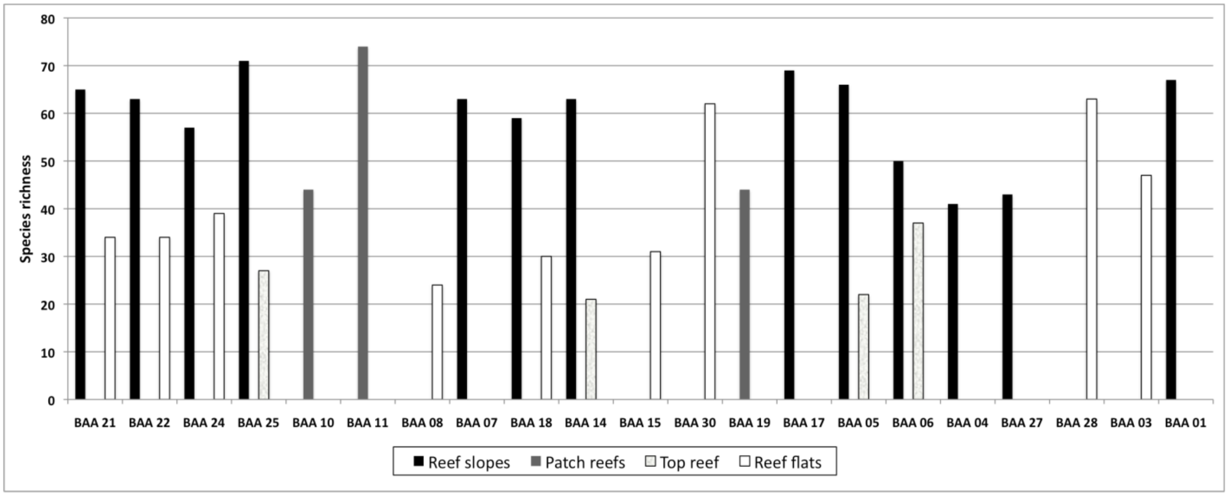


Figure 3. Coral species richness (S) recorded for the 21 sampled sites in Baa Atoll in June 2009 (Fig. **1).**

Three main families dominated coral communities: Acroporidae, Faviidae and Agaricidae. All together, they represented more than 70 % of the recorded species. The family composition of the different sites is presented in Figure 4.

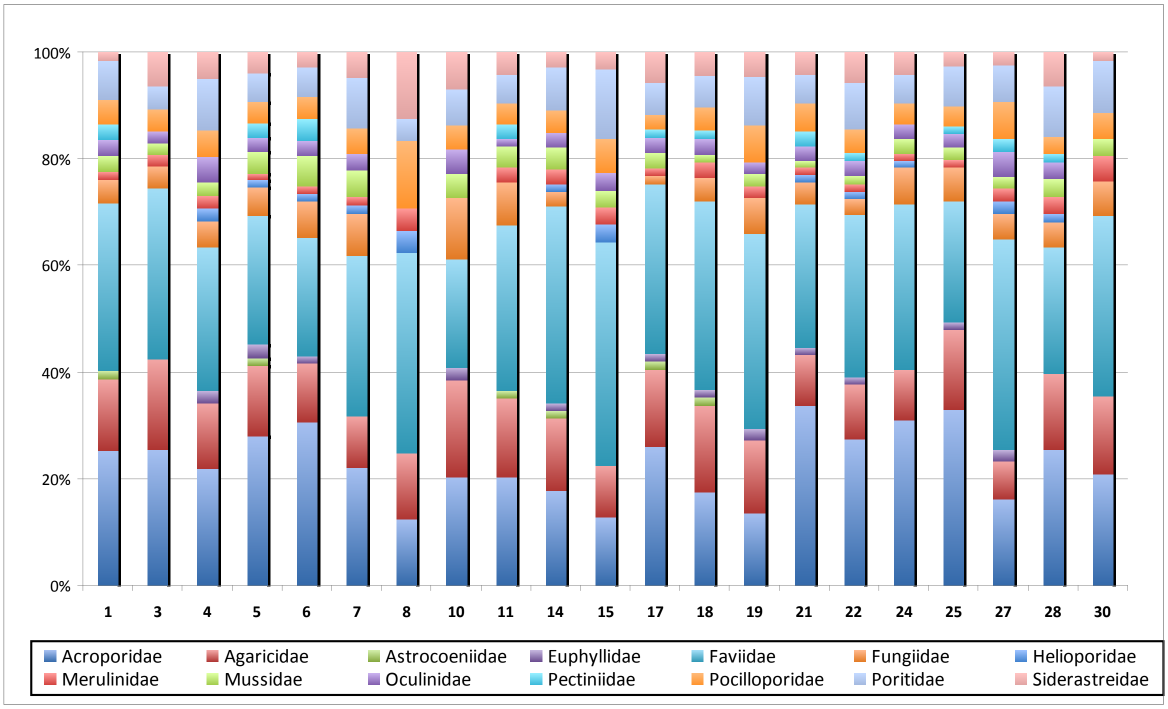


Figure 4. Distribution of coral families (in %) for the 21 sampling sites.

The richness composition of stations located in the central part of Baa Atoll (sites 5, 6, 21, 22, 24, 25) were dominated by *Acropora* communities (> 30 %) followed by Faviidae and Agaricidae. Stations located in the North /North East (sites 7, 8, 18, 19, 14, 15) and the west part of the atoll (sites 27, 28) were mostly dominated by Faviidae and Agaricidae. On each station, other coral families represented often less than 10 % of the total assemblage, but have an important contribution to the Baa Atoll coral diversity.

In terms of community composition, nMDS plots (stress values ranging 0.18, Clark, 1993) display the similarities between sites according to habitats (Fig. 5a) and oceanic vs lagoon location (Fig. 5b). The nMDS suggest grouping according to geomorphology. Indeed, differences among reef habitats were significant (R= 0,44, p < 0.001) with higher similarities between reef slopes and patches and between reef flats and top reefs (Fig. 5b). There are no evidences of grouping according to locations and exposure on the atoll (South, North, West, East) (not shown). However, differences between oceanic and lagoonal communities are evidenced in Figure 5b, although there is a clear overlap. Differences between the two groups were significant (R= 0,34, p < 0.001).

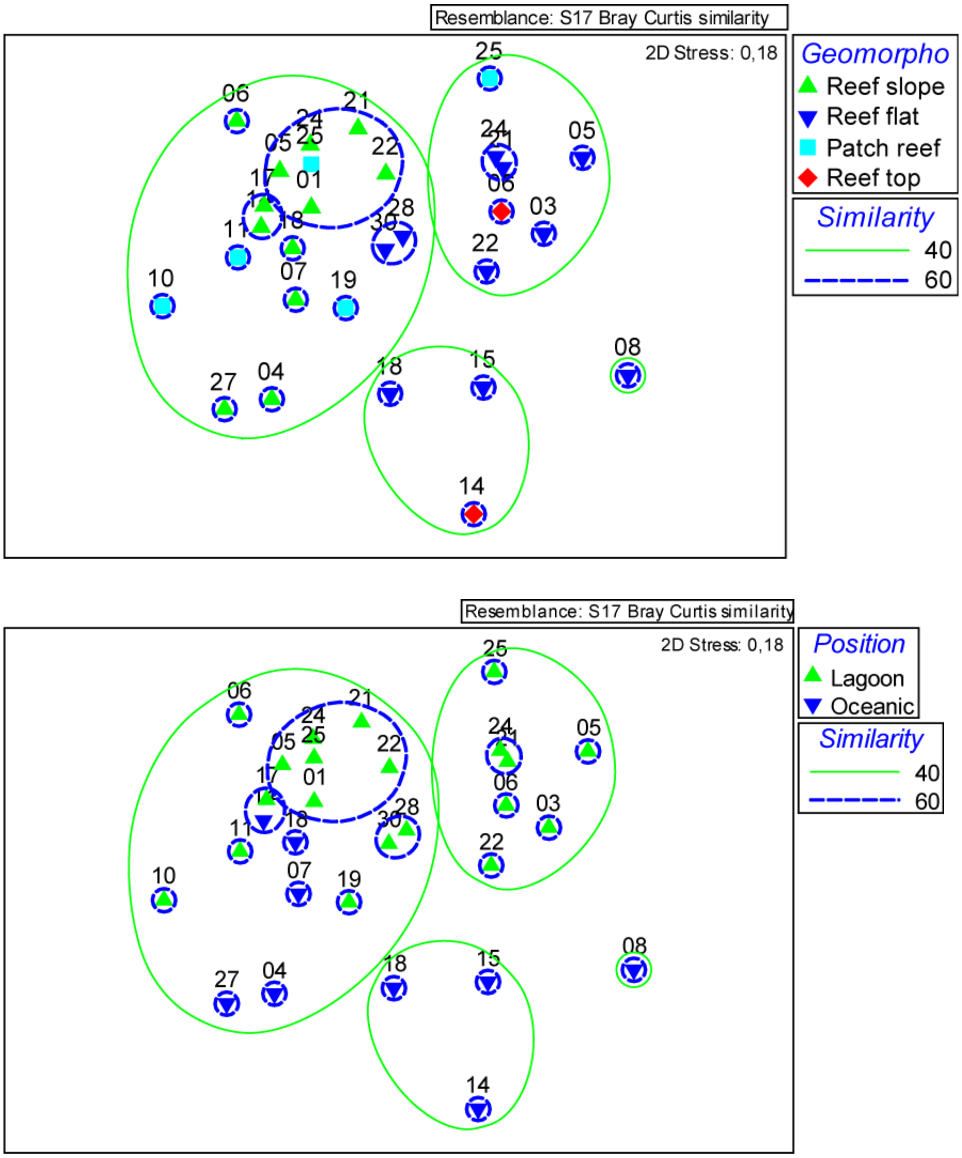


Figure 5 : Ordination by non-metric multidimensionnal scaling (nMDS) plot of Bray-Curtis similarities for presence / absence coral species data. 5a) Symbols refer the type of coral habitats and coloured lines denote the grouping of sites for a given similarity threshold. 5b) Symbols refer the location (lagoon and oceanic) and colored lines denote the grouping of sites for a given similarity threshold.

CONCLUSION

The Scleractinia of Baa Atoll were remarkably diverse, even in the present state of knowledge with 26 unidentified coral samples (Acroporidae and Favidae) and without investigations of the mesophotic deeper parts of the passes and lagoon. Additional surveys would certainly reveal the presence of other typical species adapted to these environments and which are known to have a broad geographical distribution range throughout the Indian Ocean. This point has been also highlighted by several authors for other atolls and confirmed that investigations on coral biodiversity in the Maldives should continue with a special emphasis on specific coral habitats or remote atolls not yet investigated.

Specifically for Baa, this study, stratified by the main reef geomorphological habitats, complete the previous rapid assessment by Le Berre et al. (2009) that estimated only cover and growth forms without detailed taxonomic assessment. Overall, for the reef sites sampled here, richness appear high to exceptional. Young communities (sensu Lasagna et al; 2010) present in reefs and faros in the center of the atoll appeared remarkable both in species richness and abundance. It is thus expected that this study will contribute to future decision making for conservation and zoning of Baa Atoll (Hamel and Andréfouët, this issue)

ACKNOWLEDGMENTS

This work is a contribution to the program "Biodiversity of Indian Ocean Islands" of the French Fondation pour la Recherche sur la Biodiversité. The authors acknowledge M. Pichon, G. Faure for guidance and encouragements throughout this work. Thanks to S. Andréfouët for revising an earlier draft. Gratitude is expressed to the Marine Research Center (Hussain Zahir, Shilam Adam) for scientific collaboration during the field survey, and to the Atoll Ecosystem Conservation Project for funding. We also wish to thank Thomas Le Berre and all the NOAH ship crew members for providing logistic and diving support.

REFERENCES

Benzoni, F. & Pichon M.
2007. Taxonomic re-appraisal of zooxanthellate Scleractinian Corals in the Maldive Archipelago. *Zootaxa* 1441 : 21-33
Clarke KR.
1993. Non Parametric multivariate analysis of change in community structure. *Australian Journal of Ecology* 18 : 35-46.
Clarke KR. & Warwick RM.
2001. Changes in marine communities: an approach to statistical analysis and interpretation, 2nd edn. PRIMER-E Ltd, Plymouth Marine Laboratory

Clarke KR. & Goorley RN.

2006. PRIMER v6: User manual / Tutorial. (PRIMER - E Ltd, Plymouth, United Kingdom).

Hamel, M., and S. Andréfouët

2012. Biodiversity-based propositions of conservation areas of Baa Atoll, Republic of Maldives. *Atoll Research Bulletin* 590: 223-235

Lasagna, R., Albertelli G., Colantoni P., Morri C., Bianchi CN.

2010a. Ecological stages of Maldivian reefs after the coral mass mortality of 1998. *Facies* 56 : 1-11.

Lasagna, R., Albertelli G., Morri C., and C.N. Bianchi

2010b. Acropora abundance and size in the Maldivian six years after the 1998 mass mortality : patterns across reef typologies and dephts. *Journal of the Marine Biological Association of the United Kingdom* 90 : 919-922.

Le Berre T., Emanuelli E., Roussel E., Guignard C., Sivad A., Saleem M., Zahir H.

2009. Rapid Marine Ecological Baseline Assessment of Islands of Baa atoll. Technical report SEAMARC, 156 pp.

McClanahan T.R.

2000. Bleaching damage and recovery potential of Maldivian coral reefs. Marine *Pollution Bulletin* 40 - 7: 587-597.

Pillai, C.S.G. & Scheer, G.

1976. Report on the stony corals from the Maldive Archipelago. *Zoologica*, 126, 1-83, Pl 1-31.

Rajasuriya A, Venkataraman K., Mulley E., Zahir H., Cattermoul B.

2002. Status of coral reefs in South Asia: Bangladesh, India, Maldives, Sri Lanka. In: Wilkinson CR, (eds) Status of coral reefs of the world 2002 GCRMN. Australian Institute of Marine Science, Townsville, pp 111–121.

Sheppard C.R.C.

1987. Coral species of the Indian Ocean and adjacent seas : A synonymized compilation and some regional distributional patterns. *Atoll Research Bulletin*, 307 : 1-32.

Sheppard C.R.C., A. Harris and A.L.S. Sheppard.

2008. Archipelago-wide coral recovery patterns size 1998 in the Chagos Archipelago, central Indian Ocean. *Marine Ecology- Progress Series*, 362 : 109-117.

Veron, J.E.M.

2000. Corals of the World. Australian Institute of Marine Science, Townsville, 3 vol.

Wallace, C.C

1999. Staghorn corals of the world. CSIRO publishing, Australia, 421 p.

Wallace, C.C, Zahir H.

2007. The "Xarifa" expedition and the atolls of the Maldives, 50 years on. *Coral Reefs* 26: 3-5

Zahir H, Allison W, Dews G, Gunn J, Rajasurya A, Tamelander J, Solant JL, Sweatman H., Thompson A, Wakeford M.

2006. Post-tsunami status of the coral reefs of the silands and atolls of the Maldives. In: Wilkinson CR, Souter D, Goldberg J (eds) Status of coral reefs in tsunami affected countries: 2005. Australian Institute of Marine Science, Townsville, pp 111–120.

APPENDIX

Table 1: List of Scleractinian recorded during this study, for each station (1=presence)

	SITES	1	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28	30
ACROPORIDAE - Verrill, 1902																						
Acropora austera	(Dana, 1846)	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0
Acropora abrotanoides	(Lamarck, 1816)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1
Acropora aculeus	(Dana, 1846)	1	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Acropora acuminata	(Verrill, 1864)	0	0	0	1	1	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0
Acropora austera (ref 2)	(Dana, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Acropora cerealis	(Dana, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Acropora cf. grandis	(Brook, 1892)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1
Acropora cf. millepora	(Ehrenberg, 1834)	1	1	0	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	0	1	1
Acropora selago	(Studer, 1878)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Acropora verweyi	(Veron & Wallace, 1984)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Acropora clathrata	(Brook, 1881)	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
Acropora cytherea	(Dana, 1846)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	1	0	0	0
Acropora digitifera	(Dana, 1846)	0	1	1	1	1	1	1	0	1	1	0	1	0	1	1	0	1	1	0	1	1
Acropora divaricata	(Dana, 1846)	0	0	0	1	0	1	0	0	1	0	0	1	1	0	1	1	1	1	0	0	0
Acropora elseyi	(Brook, 1892)	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
Acropora florida	(Dana, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Acropora gemmifera	(Brook, 1892)	0	1	1	0	1	1	1	0	1	0	1	0	0	0	1	1	1	1	1	0	0
Acropora granulosa	(Milne Edwards & Haime, 1860)	1	0	0	1	1	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0
Acropora granulosa (ref. 2)		1	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0
Acropora humilis	(Dana, 1846)	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1
Acropora hyacinthus	(Dana, 1846)	1	1	0	1	1	1	0	1	0	1	0	1	0	1	1	1	1	1	0	1	1
Acropora cf. longicyathus	(Milne Edwards & Haime, 1860)	1	0	0	1	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	0	0
Acropora muricata	(Linnaeus, 1758)	1	1	0	1	1	0	0	0	0	0	0	1	0	0	1	1	1	1	0	1	1
Acropora muricata (ref. 2)		0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0
Acropora muricata (ref. 3)		1	0	0	1	1	0	0	0	0	0	0	1	1	0	1	1	1	1	0	0	0
Acropora nasuta	(Dana, 1846)	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
Acropora nasuta (ref. 2)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Acropora palifera	(Lamarck, 1816)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1
Acropora paniculata	(Verrill, 1902)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Acropora robusta	(Dana, 1846)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
Acropora rudis	(Rehberg, 1892)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acropora samoensis	(Brook, 1891)	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acropora sp (ref. 10)		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Acropora sp (ref.5)		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acropora sp (ref. 7)		0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acropora sp (ref. 8)		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Acropora sp (ref. 9)		0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Acropora sp (ref. 1)		1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0
Acropora tenuis	(Dana, 1846)	1	1	0	1	1	0	0	0	1	0	0	1	0	0	1	1	1	1	0	1	1
Astreopora myriophthalma	(Lamarck, 1816)	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	1	1	1	1	1	1
Astreopora cf. ocellata	(Bernard, 1896)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Montipora aequituberculat	(Bernard, 1897)	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Montipora floweri	(Wells, 1954)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	1	0
Montipora sp (ref. 4)		0	0	0	0	1	0	0	0	1	1	0	1	1	0	0	0	0	1	1	0	0
Montipora sp (ref. 5)		1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0
Montipora sp (ref. 6)		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Montipora sp (ref. 1)		1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	0

Table 1 (Con’td)

SITES		1	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28	30
Montipora sp (ref. 2)		0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0
Montipora sp (ref. 3)		0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0
Montipora undata	(Bernard, 1897)	1	1	1	1	1	1	0	0	1	0	0	1	1	0	0	1	0	1	0	0	0
Montipora venosa	(Ehrenberg, 1834)	0	0	0	1	0	0	1	0	1	0	0	0	0	0	1	1	0	0	0	1	0
Montipora venosa (ref. 2)		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Montipora verrucosa	(Lamarck, 1816)	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1
AGARICIDAE - Gray, 1847																						
Gardineroseris explanulata	(Dana, 1846)	1	1	0	1	1	0	0	0	1	1	0	1	1	0	1	1	1	1	0	1	0
Leptoseris cf scabra	(Vaughan, 1918)	1	0	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	0	1	1
Leptoseris hawaiensis	(Vaughan, 1907)	1	0	0	1	1	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0
Leptoseris mycetoceroides	(Wells, 1954)	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0	1
Leptoseris sp		0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Leptoseris yabei	(Pillai & Scheer, 1976)	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Pachyseris speciosa	(Lamarck, 1846)	1	0	1	1	1	0	0	1	1	1	0	1	1	0	0	1	0	1	1	1	1
Pavona clavus	(Dana, 1846)	1	1	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0
Pavona explanulata	(Lamarck, 1816)	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1
Pavona maldiviensis	(Gardiner, 1905)	1	0	0	1	0	1	0	1	1	0	0	0	1	0	0	0	1	1	0	1	1
Pavona minuta	(Wells, 1954)	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Pavona varians	(Verrill, 1864)	1	1	0	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1
Pavona venosa	(Ehrenberg, 1834)	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1
ASTROCOENIIDAE - Koby, 1890																						
Stylocoeniella guntheri	(Bassett-Smith, 1890)	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0
Stylocoeniella armata	(Ehrenberg, 1834)	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DENDROPHYLLIIDAE - Gray, 1847																						
Turbinaria mesenterina	(Lamarck, 1816)	0	1	1	1	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	1	0
Turbinaria stellulata	(Lamarck, 1816)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Turbinaria peltata	(Esper, 1794)	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Tubastrea aurea	(Quoy & Gaimard, 1833)	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	0	1	0	0	1
Tubastrea micrantha	(Ehrenberg, 1834)	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	1
EUSMILIIDAE - Milne Edwards & Haime, 1857																						
Euphyllia glabrescens	(Chamisso & Eysenhardt, 1821)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphyllia ancora	(Veron & Pichon, 1979)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physogyra lichtenschteni	(Milne Edwards & Haime, 1851)	0	0	0	1	0	0	0	1	0	1	0	1	1	1	1	1	0	1	1	0	0
Plerogyra sinuosa	(Dana, 1846)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAVIIDAE - Gregory, 1900																						
Barabattoia laddi	(Wells, 1954)	1	0	1	0	1	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0
Diploastrea heliopora	(Lamarck, 1816)	1	0	1	0	0	1	0	0	1	1	0	1	1	1	0	0	1	0	0	0	1
Echinopora gemmacea	(Lamarck, 1816)	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	1	0
Echinopora hirsutissima	(Milne Edwards & Haime, 1849)	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0
Echinopora lamellosa	(Esper, 1795)	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1
Echinopora horrida	(Dana, 1846)	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1
Favia favus	(Forskal, 1775)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0
Favia helianthoides	(Wells, 1954)	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0

Table 1 (Con'td)

	SITES	1	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28	30
Favia matthai	(Vaughan, 1918)	0	1	0	0	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	0	1
Favia rotumana	(Gardiner, 1899)	0	1	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	1	1
Favia rotundata	(Veron & Pichon & Wijsman, 19	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
Favia pallida	(Dana, 1846)	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
Favia speciosa	(Dana, 1846)	1	0	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	0	0	1
Favia stelligira	(Dana, 1846)	1	0	0	1	0	1	0	0	1	1	0	1	1	0	1	1	1	1	0	1	1
Favia veroni	(Moll & Borel-Best, 1984)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Plesiastrea versipora	(Lamarck, 1816)	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0
Favites pentagona	(Esper, 1794)	0	0	1	1	0	1	1	1	0	1	1	1	1	1	0	1	0	1	0	1	1
Favites abdita	(Ellis & Solander, 1786)	1	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1	1	1	0	0	1
Favites halicora	(Ehrenberg, 1834)	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1
Favites russeli	(Wells, 1954)	1	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	1	1	1	0	0
Favites cf. spinosa		0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Favites flexuosa	(Dana, 1846)	1	0	0	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	1	0	0
Favites peresi	(Faure & Pichon, 1978)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Favites sp (ref 1)		0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cyphastrea chalcidicum	(Forskal, 1775)	1	1	0	1	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0	0	0
Cyphastrea seralia	(Forskal, 1775)	1	0	0	0	1	1	0	0	0	1	0	1	0	0	1	0	1	1	1	1	1
Cyphastrea microphthalma	(Lamarck, 1816)	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Goniastrea pectinata	(Ehrenberg, 1834)	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1
Goniastrea retiformis	(Lamarck, 1816)	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Goniastrea sp (ref. 2)		1	0	1	0	1	1	0	0	1	1	0	1	1	1	1	0	0	0	1	0	0
Goniastrea edwardsi	(Chevalier, 1971)	0	1	0	0	1	1	0	0	1	1	1	1	1	0	0	1	1	1	0	0	0
Leptastrea pruinosa	(Crossland, 1952)	1	0	0	1	1	1	0	0	1	0	0	1	1	1	1	0	0	0	1	1	1
Leptastrea transversa	(Klunzinger, 1879)	1	1	0	1	1	1	1	1	0	1	1	0	1	0	1	1	1	1	0	0	1
Leptastrea sp (ref. 1)		0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Leptastrea sp (ref 2)		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Leptoria phrygia	(Ellis & Solander, 1786)	0	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1	1
Montastrea annuligera	(Milne Edwards & Haime, 1849)	0	1	0	1	0	1	0	0	0	0	0	1	1	0	0	1	0	0	1	0	1
Montastrea magnistellata	(Chevalier, 1971)	1	0	0	1	1	1	0	0	1	1	0	1	1	1	0	1	1	0	0	0	1
Montastrea valenciennesi	(Milne Edwards & Haime, 1849)	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Montastrea curta	(Dana, 1846)	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Oulophyllia crispa	(Lamarck, 1816)	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0
Platygyra daedalea	(Ellis & Solander, 1786)	0	0	0	0	1	0	1	0	0	1	1	1	0	0	1	1	1	0	1	0	0
Platygyra pini	(Chevalier, 1971)	0	0	0	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	0	0	1
Platygyra lamellina	(Ehrenberg, 1834)	1	0	1	1	0	1	0	1	1	0	0	1	0	1	0	1	1	1	1	1	0
Platygyra sinensis	(Milne Edwards & Haime, 1849)	1	1	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	1
FUNGIIDAE - Dana, 1846																						
Fungia fungites	(Linnaeus, 1758)	1	1	1	1	1	0	0	0	1	0	0	1	1	1	1	1	1	1	0	1	1
Fungia (cycloseris) sp		0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0
Fungia sp (ref. 2)		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Fungia scutaria	(Lamarck, 1801)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fungia klunzingeri	(Doderlein, 1901)	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Fungia paumotensis	(Stuchbury, 1833)	0	1	1	1	0	1	0	1	1	1	0	0	0	1	0	0	1	0	1	1	1
Fungia horrida	(Dana, 1846)	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Halomitra pileus	(Linnaeus, 1758)	0	0	0	1	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	1	0
Herpolitha limax	(Esper, 1797)	0	0	0	1	1	0	0	0	1	0	0	0	1	0	1	1	1	1	1	0	1

Table 1 (Con'td)

	SITES	1	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28	30
Sandalolitha dentata	(Quelch, 1884)	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1
Cycloseris sp		0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
HELIOPORIDAE - Pallas, 1766																						
Heliopora coerulea	(Pallas, 1766)	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	0	1	1	0
MERULINIDAE - Verrill, 1866																						
Hydnophora microconos	(Lamarck, 1816)	0	1	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	1	1
Hydnophora exaesa	(Pallas, 1766)	0	0	1	1	0	1	0	0	0	1	0	1	1	1	1	0	0	1	1	1	1
Merulina ampliata	(Ellis & Solander, 1786)	1	0	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0	0	1
MUSSIDAE - Ortmann, 1890																						
Acanthastrea echinata	(Dana, 1846)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Lobophyllia corymbosa	(Forskal, 1775)	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	1
Lobophyllia hemprichii	(Ehrenberg, 1834)	1	1	0	1	1	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0	1
Cynarina lacrimalis	(Milne Edwards & Haime, 1849)	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
Symphyllia recta	(Dana, 1846)	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
Symphyllia radians	(Milne Edwards & Haime, 1849)	0	0	0	1	1	1	0	0	1	1	1	1	1	1	0	0	0	0	0	1	0
Symphyllia agaricia	(Milne Edwards & Haime, 1849)	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
OCULINIDAE - Gray, 1847																						
Galaxea fascicularis	(Lamarck, 1816)	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Galaxea astreata	(Linnaeus, 1758)	1	0	1	1	1	1	0	1	0	1	0	1	1	0	1	1	1	1	1	1	0
PECTINIIDAE - Vaughan & Wells, 1943																						
Echinophyllia aspera	(Ellis & Solander, 1786)	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0
Mycedium elephantotus	(Pallas, 1766)	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Oxypora lacera	(Verrill, 1864)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Pectinia lactuca	(Pallas, 1766)	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0
POCILLOPORIDAE - Gray, 1842																						
Pocillopora damicornis	(Linnaeus, 1758)	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Pocillopora verrucosa	(Ellis & Solander, 1786)	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Pocillopora meandrina	(Dana, 1846)	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Pocillopora eydouxi	(Milne Edwards & Haime, 1849)	1	0	0	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	0
PORITIDAE - Gray, 1842																						
Alvepora sp1		1	0	1	1	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	1
Goniopora stokesi	(Milne Edwards & Haime, 1851)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0
Goniopora djiboutiensis	(Vaughan, 1907)	1	0	1	0	1	1	0	1	0	1	1	1	0	1	0	1	0	0	0	0	1
Goniopora columna	(Dana, 1846)	0	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0
Goniopora stutchburryi	(Wellsl, 1955)	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0
Goniopora sp (ref. 3)		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Porites lutea	(Milne Edwards & Haime, 1860)	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
Porites synarea rus	(Forskal, 1775)	1	0	0	1	1	1	0	0	0	1	0	0	0	0	1	1	1	1	0	1	1
Porites lobata	(Dana, 1846)	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0	0	0	1	1
Porites cylindrica	(Dana, 1846)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Porites solida	(Forskal, 1775)	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	0

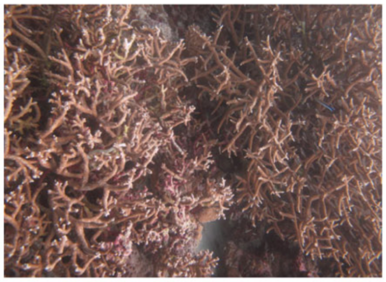
Table 1 (Con'td)

SITES		1	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28	30
SIDERASTERIDAE - Vaughan & Wells, 1943																						
Coscinarea monile	(Forskal, 1775)	0	0	1	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0
Coscinarea sp (ref. 2)		0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Psammocora profundacell	(Gardiner, 1898)	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0
Psammocora contigua	(Esper, 1797)	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	1	1	1	0	1	0
Psammocora digitata	(Milne Edwards & Haime, 1851)	0	1	0	1	1	1	1	0	0	0	0	1	0	0	1	1	1	0	0	1	1
Psammocora cf. haimenea	(Milne Edwards & Haime, 1851)	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	1	0	0	0	1	0

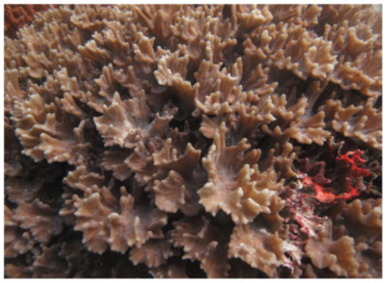
Plate 1

Psammocora digitata

Acropora muricata



Acropora cf. muricata

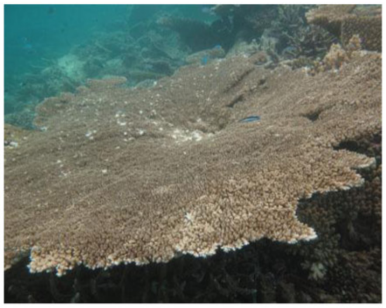


Pectinia paeonia

Echinopora horrida

Goniopora cf. columna

Plate 2



Acropora hyacinthus

Mycedium elephantotus

Acropora assemblage

Acropora clathrata

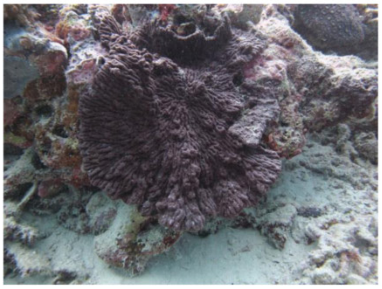
Hydnophora microconos

Protopalythoa sp.

Plate 3

Acropora tenuis

Lobophyllia corymbosa



Merulina ampliata

Acropora muricata assemblage

Pocillopora verrucosa

Reef flat of central faro reef

Photographs by*: Hani AMIR (MRC) et Lionel BIGOT (ECOMAR)*

HYDROIDS (CNIDARIA, HYDROZOA) OF BAA ATOLL (INDIAN OCEAN, MALDIVES ARCHIPELAGO)

BY

NICOLE GRAVIER-BONNET AND CHLOÉ A-F. BOURMAUD

ABSTRACT

This study provides the first description of hydroid species and communities in Baa Atoll. 22 stations from 0 to 30 meters depth (except one at 50) were visited based on contrasted geomorphology, and 568 benthic specimens collected. Preliminary results provided a provisional list of 115 species, of which 100 are new records for the Maldives Archipelago. The hydroid fauna of Baa Atoll consists of 74% leptothecates and 26% antoathecates, and represents 26 families and 43 genera. Besides the Eudendriidae (7 spp), the most speciose families (>10 spp) were the Aglaopheniidae, Campanulariidae, Halopterididae, Haleciidae and Sertulariidae. Several new species are suspected but additional material and/or more taxonomic studies are required to complete the descriptions. The more common species are documented by underwater and laboratory photographs (29 spp), with a focus on aglaophenids. The species richness was high and well distributed in the varied locations visited. Richness was higher on atoll rim faro than inside the atoll. Richness was also higher on outer slopes and passes than reef flats and inner reefs of rim faro. The absence of *Aglaophenia cupressina* and of the fire corals *Millepora* was noticed. Combining records gathered from old literature data and those of this Baa Atoll study, the hydroid species richness in the Maldives reaches 160 spp, which is high like in other Indian Ocean islands.

INTRODUCTION

Only three scientific articles, published at the very beginning of the 20th century, concern the Maldives Archipelago Hydrozoa (Bigelow, 1904; Browne, 1904; Borradaile, 1905). Browne and Borradaile studied respectively specimens of medusae and polyps collected during the oceanographic expedition (1899-1900) of J. Stanley Gardiner who published “The Fauna and Geography of the Maldives and Laccadive Archipelagoes” in 1904. Bigelow studied medusae going from the steamer “Amra” expedition (1901-1902) related by Alexander Agassiz (1903). Hydroid colonies were mainly obtained by dredging. From a depth of 37-77 m (except for one littoral), Borradaile (1905) described 23 species of hydropolyps of the orders Anthoathecata and Leptothecata, including 7 new

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species. Medusae were taken off mainly by plankton surface hauls. Bigelow (1904) and Browne (1904) reported respectively 13 and 7 species of hydromedusae (Anthomedusae, Leptomedusae and Limnomedusae), with none in common among them, and none as well with Borradaile. In addition, these two authors reported a few species belonging to other hydrozoan groups with holoplanctonic life cycle (Trachymedusae, Narcomedusae and Siphonophores). These taxa are not taken into consideration in the present study that focuses on the benthic fauna.

This historical knowledge yields a list of 43 species for the orders Anthoathecata (12), Leptothecata (29) and Limnomedusa (2), 23 from polyps and 20 from jellyfishes. While no other dedicated research on the Maldives hydrozoans was done to our knowledge, scattered additional data have been found. The John Murray expedition in the Indian Ocean, which essentially concerned the deep waters, provided four additional species, including a new one (Rees & Vervoort, 1987). For the peculiar families having a calcareous skeleton, the Milleporidae and the Stylasteridae, data are found separately, as these families are usually studied together with calcareous hard corals. Boschma (1948) summarizing old knowledge on the milleporids reported the single species *Millepora platyphylla* Hemprich & Ehrenberg, 1834 in the Maldives, while more recent studies mentioned also branched species like *Millepora latifolia* Boschma, 1948 and *Millepora tenera* Boschma, 1948 (Wells & Davies, 1966 in Stoddart, 1966; Lewis, 2006). Regarding stylasterids, Broch (1947) reported two species of the genus *Crypthelia* from deep areas (200-900m), and Wells & Davies (1966) and Scheer & Obrist (1986) two other species from shallow waters, *Distichopora fisheri* Broch, 1942 and *Distichopora nitida* Verrill 1864, respectively. Finally, marine life identification books on Maldives fauna and flora include imprecise data but good photographs of hydrozoans (Anderson, 1991; Coleman, 2000). This review indicates that the known species richness in the Maldives was 60 prior to this study (38.3% anthoathecates, 58.3% leptothecates, and 3.3% limnomedusae, with 18 species known as a medusa only), a low number in respect to the wide marine area covered by Maldivian reefs.

During a biodiversity survey carried out in 2009 in Baa Atoll (center West of the Maldives Archipelago), an inventory of the hydroid fauna was done to update knowledge on marine biodiversity of the Man and Biosphere UNESCO Reserve of Baa Atoll (Jimenez et al, submitted). The results are presented here with the aims to (1) quantify species richness, (2) establish a preliminary list of species, (3) analyze the composition of the hydroid fauna, and (4) provide photographs for the macroscopic species most easily seen while scuba-diving, with a focus on the family Aglaopheniidae. This is the first extensive study of benthic hydroids conducted in the Maldives Archipelago.

MATERIAL AND METHODS

From 23rd May to 5th June 2009, a collection of hydroids was made in shallow waters around Baa Atoll from the boat NOAH, at the beginning of the Southwest monsoon. Baa Atoll, circa 40 km long and wide, has a discontinuous rim. It is located in the western side of the Maldives Archipelago at 5° 11′ N and 72° 59′ E (Fig. 1). Twentytwo stations were sampled for benthic hydroids, 21 of which between 0 and 30 meters in depth and one (Station 23) at 50 m (Fig. 1).

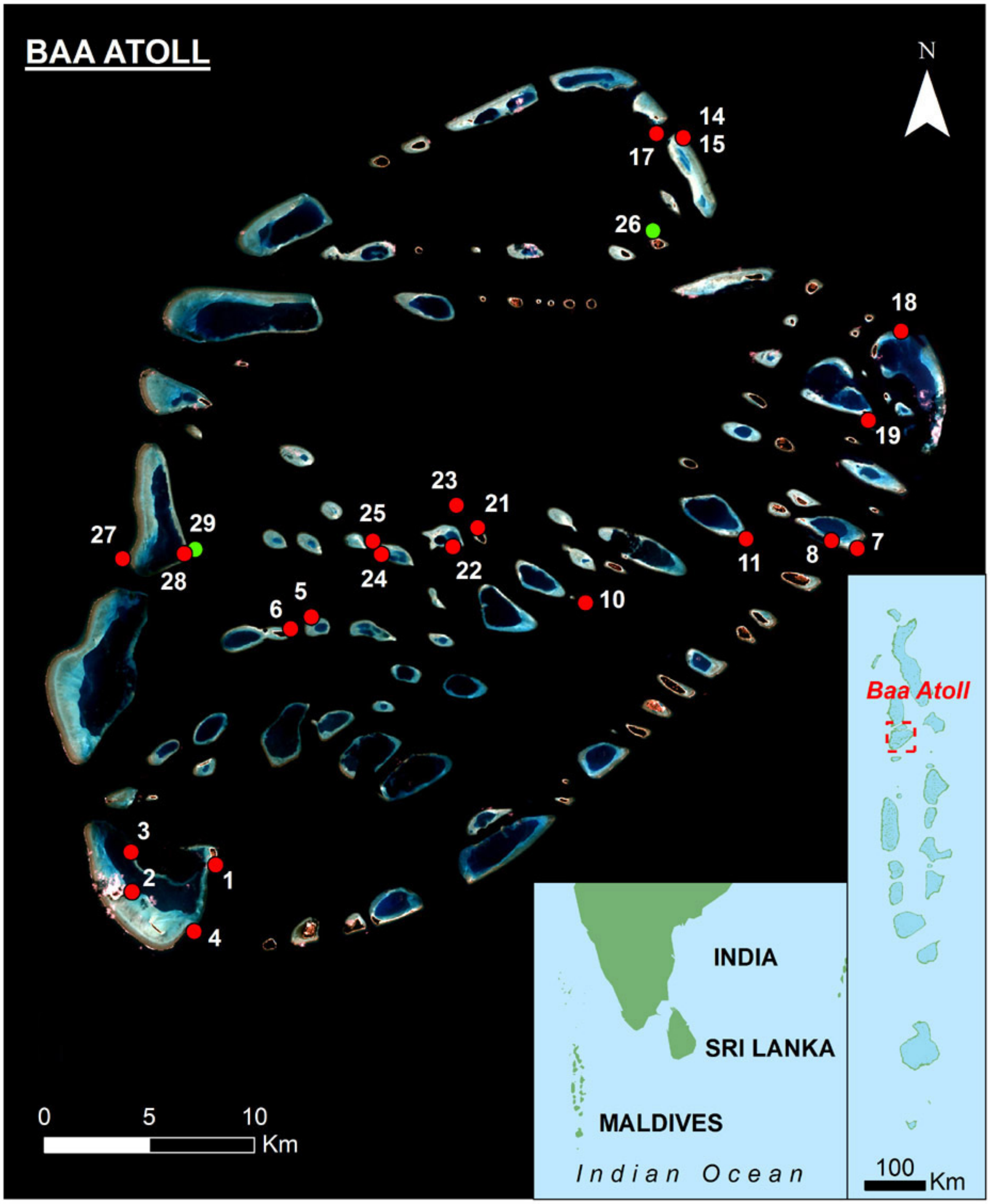


Figure 1. Geographic location of the Maldives Archipelago and Baa Atoll, and sampling stations in Baa Atoll. Six geomorphologic units were differentiated: reef flats of rim faro (2, 8, 15), inner reefs of rim faro (3, 28), lagoon pinnacles, patch reefs/channels and ridge (10, 11, 19, 25), fore reefs of lagoon faro (5, 6, 21, 22, 24), passes of rim faro (1, 4, 17) and outer slopes of rim faro (7, 14, 18, 27). Station 2 was a seagrass bed that yielded no specimen. Two plankton sampling stations (26 and 29) are not studied here (medusae).

Benthic hydroid colonies and pieces of varied substrata supporting or susceptible to support small and microscopic colonies (invertebrates, algae, sea-grasses, limestone, hard bio-constructed substratum…) were collected by hand or with a hammer and a chisel, either by SCUBA diving or snorkeling. Many colonies were of a small size though visible enough to be distinguished underwater. Many other specimens were found only by microscopic observation.

Samples were stored in plastic boxes underwater and when on board disposed in glass dishes with clean seawater renewed frequently. Sorting was done under stereomicroscopes (Leica M3Z) while animals were still alive, and this was augmented by examination with a monocular compound microscope when necessary. Specimens were then fixed in 3% formalin in seawater, and in many cases sub-samples were fixed in ethanol for further genetic studies. Underwater photographs of the largest colonies were taken (Canon Ixus 65). Microphotographs were taken on the boat with a Sony Cybershot DSC-X230. All pictures are from the authors except one from J-L. Menou (see *Gymnangium hornelli* underwater photograph in Appendix 3). Student-Newman-Keuls (SNK) statistical tests were performed with R 2.14.1.

RESULTS

Species Richness and Community Structure

The sampling effort led to a total of 568 benthic specimens. The major part were collected and fixed, and are now gathered at the University of La Réunion. While further refinement is possible, we record 115 hydroid species, 85 leptothecates (74%) and 30 anthoathecates (26%), distributed in 43 identified genera and 26 families (Table 1). No specimen of the order Limnomedusae was found. A preliminary list of species is given in Appendix 1.

Table 1. Distribution of the number of species, genera and families.

	Families	Genera	Species
Anthoathecates	13	17	30
Leptothecates	13	26	85
TOTAL	26	43	115

The most speciose families of this collection are the Aglaopheniidae, Campanulariidae, Haleciidae, Halopterididae and Sertulariidae, for the leptothecates (>10 spp), and the Eudendriidae and Oceaniidae for the anthoathecates (>5 spp). The most speciose genera (>5 spp) are *Clytia*, *Eudendrium*, *Halecium* and *Halopteris*.

Distribution of the Species Richness Inside the Atoll

In the 22 benthic stations (Fig. 1), the hydroid species richness was relatively equally distributed (Table 2). The exception is station 2 where no hydroid was found in the shallow sea grass bed next to the village of Thulhaadhoo. In the deepest station (23 at 50 m deep) the collecting event only lasted a few minutes, so we consider that the 6 species sampled may not indicate the true species richness of this station. Thus, the distribution of the hydroid species richness is further calculated without taking into account these stations 2 and 23.

The 20 remaining stations included at least 10 species, and 55% exhibited more than 20 species, with a maximum of 33 species for station 7 (east outer slope of rim faro, 0-30 m). The average per station is 21.4 species. The stations 1, 4, 5, 7, 11, 14, 17, 18 and 27 were the most diversified, with at least 25 species sampled. These stations corresponded to outer slopes and passes of the rim faro all around the atoll, except for station 5 which was a fore reef of lagoon faro and station 11 which was a deeper lagoon pinnacle. Station 28 (3-8 m deep, inner reef of rim faro) was the most depauperate because the sandy bottom habitat, dominant there, was inappropriate for benthic hydroid settlement. Four stations having a relative low number of species are located on reef flats of rim faro (stations 8 and 15) and into the lagoon (pinnacle 25 and fore reef 21).

Table 2. Species richness (SR) per station.

Baa stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28	Mean ±SE*
SR	25	0	18	27	26	19	33	14	17	28	27	16	27	27	21	15	17	6	22	14	25	10	21.4±1.4

* mean and standard error (SE) without the stations 2 and 23 (cf. text)

Regrouping the stations according to their geographic situation on the rim faro of the atoll (Table 3), we found no obvious change in species richness from north (50 spp), south (51 spp), east (59 spp) and west (31 spp). The SNK test showed no significant differences ($\alpha = 0.05$). While the species richness means of the rim faro stations versus inside the atoll were not significantly different, the stations from the rim faro yielded a total of 101 species (mean 22.4 spp per station) whereas merged lagoon and faro stations yielded 70 species (mean 19.9 spp per station). Fifty three species were common between lagoon and rim faro, 17 species reported only from the lagoon and 58 species reported only from the rim faro. Thus, while fairly well distributed in Baa Atoll, the species richness was higher on the rim faro versus inside the atoll.

Table 3. Species richness per station according to their geographic location (GL) (except stations n° 2 and 23).

Geographic location (number of stations)	Northern Rim faro (3)	Southern Rim faro (3)	Eastern Rim faro (4)	Western Rim faro (2)	Lagoon (8)	Rim faro (12)
Stations	14, 15, 17	1, 3, 4	7, 8, 18, 19	27, 28	5, 6, 10, 11, 21, 22, 24, 25	1, 3, 4, 7, 8, 14, 15, 17, 18, 19, 27, 28
Species richness	50	51	59	31	70	101
Mean per GL ±SE	23.3 ± 3.7	23.0 ± 2.5	23.8 ± 4.1	17.5 ± 7.5	19.9 ± 1.9	22.4 ± 1.9

The number of hydroid species per geomorphologic unit is given in Table 4 (see Fig. 1 for the station classification). The species richness mean clearly increased from the reef flats and inner reefs (14-15 spp) to the outer slopes and passes of rim faro (26-28 spp) (significant at $\alpha = 0.05$), then into the lagoon and on the fore reefs of lagoonal faro located in the center of Baa Atoll (20 species) (significant at $\alpha = 0.1$).

Table 4. Species richness per geomorphologic unit (GU) from the rim to the center (except stations n° 2 and 23).

Geomorphologic units	Outer slopes of rim faro	Passes of rim faro	Reef flats of rim faro	Inner reefs of rim faro	Lagoon pinnacles, patch reef/channel & ridge	Fore reefs of faro
(Number of stations)	(4)	(3)	(2)	(2)	(4)	(5)
Species richness	60	58	28	23	51	55
Mean per GU ±SE	28 ± 1.7	26 ± 0.6	15 ± 1.0	14 ± 4.0	20 ± 3.0	20 ± 2.1

Species Distribution

The species distribution per station is given in Appendix 2. Several species were eurybathic and widely distributed in Baa Atoll, checked in at least 50% of stations at the depth investigated (0-30 m), located from north to south and east to west (Table 5). Photographs compiled in Appendix 3 document these most common species. Among these species *Sertularella delicata* and *Thyroscyphus fruticosus* were present in 80 and 75% of samplings, respectively, and *Synthecium patulum* was found from 3 to 50 m in depth. Other species, *Antennella secundaria, Clytia latitheca, Halopteris platygonotheca, Hebella scandens* and *Macrorhynchia phoenicea,* inhabited in the range of 3-30 m

Table 5. Common hydroid species reported from different geomorphologic units, and the number of stations from each unit where the species were encountered (species order by decreasing number of total of records).

Species / geomorphologic units	Outer slopes of rim faro	Passes of rim faro	Reef flats of rim faro	Inner reefs of rim faro	Lagoon pinnacles, patch reef/ channel & ridge	Fore reefs of faro	Total
(Number of stations)	(4)	(3)	(2)	(2)	(4)	(5)	(20)
Sertularella delicata	3	2	1	2	3	5	16 (80%)
Thyroscyphus fruticosus	4	2	0	1	4	4	15
Nemalecium sp. 1	4	2	1	2	1	4	14
Dynamena crisioides	2	1	1	1	3	5	13
Gymnangium hians	4	0	1	1	3	4	13
Clytia linearis	4	3	0	0	3	2	12
Dynamena moluccana	4	0	1	2	3	2	12
Synthecium patulum	3	2	2	1	2	2	12
Pennaria disticha	2	3	0	1	2	3	11
Nemalecium lighti	2	0	0	1	2	5	10 (50%)

deep but they were reported in only 20-35% of the stations. *Lytocarpia brevirostris* and *Lytocarpia phyteuma* were more stenobathic, found between 12 and 30 m in depth, while *Macrorhynchia philippina* between 3 and 20 m.

Some species were only found on reef flats, *Plumularia strictocarpa*, *Rhizogeton* sp., while other species were encountered in deeper zones, *Gymnangium hornelli*, *Hebella muscensis,* and *Turritopsis* sp. (30 m), *Bimeria vestita* and *Synthecium* sp. (50 m). *Gymnangium gracilicaule* and *Lytocarpia brevirostris* were mainly sampled in outer slopes or passes of rim faro.

Rare and Interesting Species

Little known species have been collected during the survey. For example *Sertularia maldivensis* Borradaile, 1905, was not reported since its original description. According to Schuchert (2004), *Turritopsis chevalense* (Thornely, 1904) was not reported as well. *Macrorhynchia singularis* (Billard, 1908) is also a rare species recently reported from Indonesia (Schuchert, 2003). Conversely, *Salacia tetracythara* Lamouroux, 1816, a well known species that was reported several times in several SWIO islands where it was abundant (unpublished results and Gravier-Bonnet, 2008), was collected only once in Baa in a deep station.

We suspect that several specimens are from new species but additional taxonomic studies are needed for confirmation. One of the most interesting species, ?*Proboscidactyla* sp., is a very small colony found on the operculum of a sedentary polychete having tiny hydranths very similar to that of *Proboscidactyla* but equipped with four tentacles instead of two. To describe a new genus in the family Proboscidactylidae or change the diagnosis of the genus is not appropriate as, unfortunately, the material collected is poor and sterile. For the completion of the taxonomic study, it will be probably necessary to describe new species for at least one species of the genera *Corydendrium*, *Eudendrium, Turritopsis*, *Antennella*, *Halopteris* and *Plumularia*.

Remark

Only 31% of the 568 registered specimens were fertile, provided with features allowing one to know if they reproduce with a medusa or not, thus allowing for identification with confidence. However, in respect to the species number (115), the percentage of fertile species was 47%.

DISCUSSION

Species Richness and Community Structure: A Regional Comparison

The Maldives Archipelago occupies a large oceanographic area and an interesting location above the Equator in the middle of the Indian Ocean, close to the Indonesian center of biodiversity. However, knowledge of Hydrozoa remained limited, with only 60 species recorded since 1904 for the orders Anthoathecata, Leptothecata and Limnomedusa. The present hydroid dedicated study led to the collection of 115 species.

Among them, 100 species are new records for the Maldives (see Appendix 1), and all are new records for Baa Atoll where no investigation for hydroids was available. The compilation of the Baa list with the historical Maldives list yields an updated number of Maldivian species of around 160.

The species richness of Baa Atoll is high. Compared to other locations previously studied by the authors in the South Western Indian Ocean (Table 6), it is higher than Glorieuses and Juan de Nova Islands (Gravier-Bonnet & Bourmaud, 2006a; 2006b) and close to La Réunion (Bourmaud et al., 2006) and Mayotte, in the Comoros Archipelago (unpublished results of the authors) where past sampling effort was more thorough. In the present state of knowledge, these results indicate a range of variation in the number of species, genera and families of the IO coral reef islands of respectively 88-173, 38-63 and 21-29. The hydroid assemblage of the Siladen coral reefs (Bunaken Marine Park, North Sulawesi, Indonesia), studied on vertical 2.5-50 meters transects, enters this range as made up of 107 species belonging to 51 genera and 28 families (Di Camillo et al, 2008). Adding data of two studies of hydroids in the range of 0-25 meters in Guadeloupe (Galea, 2008, 2010), in the tropical Atlantic, lead to similar numbers for genera (41) and families (28), with a species richness only a bit lower (79). Species richness is certainly underestimated everywhere as the collecting efforts were done either on limited areas or on part of the biotopes only.

Table 6. Species richness of Baa Atoll compared with that of other coral reefs of SWIO islands (Gravier-Bonnet and Bourmaud, published and unpublished results).

	Baa/Maldives	La Réunion	Glorieuses	Mayotte	Juan de Nova
Families	26	29	21	26	26
Genera	43	61	38	63	44
Species	115/160*	160	88	173	95

* adding literature reports

Hydroid species richness in Baa Atoll is spatially well distributed, with an average of 21 species at each site. However species richness was higher on the rim faro than inside the atoll. Moreover, species richness clearly increases from the reef flats and inner reefs to the outer slopes and passes of the rim faro. This result agrees with those reported for other SWIO islands (La Réunion, Glorieuses, Juan de Nova, in Gravier-Bonnet & Bourmaud, 2006 a, b), and for Indonesia (Di Camillo et al, 2008), where the outer slope yields the highest species richness and abundance. The highest species richness of the east outer slope of Baa Atoll (station 33) could be due to specific hydrological conditions at the edge of the atoll facing the internal oceanic zone in between the east and west atoll series.

The community structure of the Baa Atoll hydroid fauna is similar to other tropical islands investigated in SWIO where leptothecates provided 72 to 75% of the hydroid species richness (Table 7). Thus, the typical hydroid community structure of both Indian Ocean tropical areas and some other areas distributed worldwide (Gravier-Bonnet & Bourmaud, 2006a; Di Camillo et al., 2008) is confirmed here, with dominance of leptothecates whereas anthoathecates represent only 19-35% of the fauna.

Table 7. Indian Ocean hydroid community structure: percentages (%) of leptothecates, and number of species for the five most speciose families (Gravier-Bonnet and Bourmaud, published and unpublished results).

	Leptothecates	Sertulariidae	Aglaopheniidae	Campanulariidae	Halopterididae
Baa	74	14	14	12	11
Réunion	73	22	15	8	10
Glorieuses	74	16	12	7	7
Juan de Nova	72	12	19	5	6
Mayotte	75	30	21	17	13

In the SWIO islands, the Aglaopheniidae and Sertulariidae were the two major families (Table 7), and the most speciose genera were either *Macrorhynchia-Gymnangium* for aglaophenids, or *Dynamena-Sertularella* for sertulariids. Even if most of their species are large and easy to detect underwater unlike small or tiny species, the present results confirm that in coral reefs of the remote tropical islands of the Indian Ocean the two families Aglaopheniidae and Sertulariidae predominate inside the hydroid fauna. Baa Atoll and Mayotte fauna is distinguished from the others by having, in addition, two other families much more diversified than elsewhere, the Halopterididae (major genus *Halopteris*), and the Campanulariidae (major genus *Clytia*). The family Haleciidae (major genus *Halecium*) is usually also well developed, including Baa Atoll (11 spp). Further extensive taxonomic studies might yield these taxa to reach the first or second range. Within anthoathecates, the family Eudendriidae was the most speciose (7 spp) in Baa like in the previously investigated islands, and so was the genus *Eudendrium*. This trend is also reported in the Siladen Island coral reefs (Sulawesi, Indonesia) where the most widely represented leptothecate families are the Sertulariidae, Aglaopheniidae, Halopterididae and Plumulariidae, while the anthoathecate ones are Zancleidae and Eudendriidae, in descending order (Di Camillo et al, 2008).

Unexpected results concern the two families with calcareous skeleton protected by the CITES convention, namely the Milleporidae and the Stylasteridae (previously named hydrocorals). Previous studies done in other atolls of the Maldives Archipelago reported (a) *Millepora* as one main reef organism in shallow (0-7 m) areas, where it built some "*Millepora* zone" (Morri et al. 1995), (b) the massive species *Millepora platyphylla* (Boschma, 1948; Coleman, 2004) and two branched species, *Millepora tenera* (Wells & Davies, 1966; Coleman, 2000; Lewis 2006) and *Millepora latifolia* (Wells & Davies, 1966). In Baa Atoll, we observed no *Millepora* zone and we reported only a single colony of *Millepora ?platyphylla* (see Appendix 1 for question mark). The 1997-98 El Niño Southern Oscillation event (ENSO) induced a strong bleaching and a massive coral mortality (of up to 90%) in the tropical Indian Ocean, including the Maldives (Wilkinson et al, 1999; McClanahan, 2000). Like scleractinians, fire corals are very sensitive to bleaching, and *Millepora platyphylla* in the Maldives was severely damaged during this worldwide event (Lewis, 2006). Only two colonies of plating *Millepora* were seen in a 1999 survey done in several central atolls of the Maldives Archipelago, whereas this genus was the fifth most common genera in 1958 (McClanahan, 2000). He also observed no branching *Millepora* species during his survey and concluded *"Millepora tenera* and *M. intricata* are among those species likely to be locally extirpated". Coral recolonization started in 1999 but no *Millepora* recruits were observed (McClanahan, 2000; Bianchi et al, 2006). By 2002, if the coral cover remained low, coral diversity had not decreased, but some previously abundant species had become rare and *Millepora* had completely disappeared (Bianchi et al, 2006; 2009). The unique *Millepora* colony found in Baa Atoll ten years after this El Niño event suggests that similar extirpation may have happened elsewhere in the Maldives Archipelago and that *Millepora* spp colonies have not been able to recover after the bleaching. Similar events in the eastern Pacific also reduced *Millepora* to such low levels that it is nearly locally extinct (Glynn & Weerdt, 1991; Glynn & Feingold, 1992). Conversely, we observed many locations characterized by abundant *Heliopora coerulea* colonies in the environment usually inhabited by milleporids. *Heliopora coerulea* was apparently not affected by SST anomalies (Bianchi et al, 2006). The single *Millepora* colony observed in Baa was not in the very shallow waters, likely explaining its survival at a time of heat stress. It brings some hope for further recolonization if a few other colonies of both sexes are present in the vicinity (Bourmaud et al., submitted). Regarding stylasterids, colonies of the two tropical shallow water species recorded, *Distichopora violacea* and *Stylaster roseus*, were rare and reported at only a few stations in Baa, while usually common and largely distributed in SWIO islands.

Surprisingly, despite the fact that the family Aglaopheniidae is one of the most speciose of the collection, the widespread species known from Indonesia to Africa, *Aglaophenia cupressina* (spelled “fire-weed” for its stinging properties) was missing from Baa Atoll, though environmental conditions were favorable. It was not previously reported in Maldives as well. Remarkably, this species is also absent from the Mascarene Archipelago, and thus seems missing from large areas located both in the North (Maldives) and in the South (Mascarene, unpublished data) of the main South Equatorial current allowing species dispersal from the Eastern hot-spot of biodiversity. Similarly, not a single species of the genus *Solanderia* was reported in Baa, although it is reported in the Maldives (Coleman, 2000) and several species of this genus are commonly found in the Indian Ocean (Bouillon et al., 1992; Vervoort, 1993; Gravier-Bonnet & Bourmaud, 2006a,b).

Other differences in the species composition of Baa, compared to the SWIO islands, is the absence of the family Kirchenpaueridae, usually represented by one species, and of some genera (*Diphasia*, *Hincksella*, *Thuiaria*) and species usually found, like the large and deep *Macrorhynchia sibogae* (Billard, 1913) and *Sertularella diaphana* (Allman, 1886), and the epizoan *Diphasia digitalis* (Busk, 1852). The rarity of *Salacia tetracythara* Lamouroux, 1816 is also noticeable. Conversely, the family Oceaniidae is well diversified and the sertularid *Sertularella delicata,* rather rare in SWIO, was very common during our survey in Baa Atoll. We hypothesize that this last species hides a species complex in the Indian Ocean, and further molecular investigations are warranted to test this.

Species Distribution

Marine phanerogames and many algae are usually good substrata for hydroids (Oliveira & Marques, 2007), as demonstrated in the Indian Ocean (Gravier, 1970; Gravier-Bonnet & Bourmaud, 2005). Surprisingly, no hydroids were found in the seagrass bed investigated in Baa Atoll. This bed was monospecific, formed by *Thalassia hemprichii*. Many species were found in monospecific *Thalassodendon ciliatum* seagrass beds in Glorieuses and Mayotte, whereas, on the opposite, only two were found in *Syringodinium isoetifolium* beds in La Réunion (unpublished data). Thus, monospecificity alone cannot explain the absence of hydroids. It might be rather the consequence of the leaves surface quality of the substratum, as some phanerogame species are more colonized by hydroids than others, for instance *T. ciliatum* compared to *T. hemprichii* (Gravier, 1970).

Comparisons with other SWIO surveys (published and unpublished authors data) allow describing hydroid species distribution and ecology on coral reefs in this region. Several Baa Atoll species collected mainly on hard substrata, are common and characteristic species of tropical Indian Ocean shallow waters. There are eurybathic species (*Dynamena crisioides*, *D. moluccana*, *Gymnangium hians, Lytocarpia phyteuma, Nemalecium* sp.1*, N. lighti, Synthecium patulum, Thyroscyphus fruticosus)*, whereas others are rather stenobathic (*Lytocarpia brevirostris*, *Macrorhynchia phoenicea*, *M. philippina*). Other species linked to currents are characteristic of outer slopes and passes (*Macrorhynchia spectabilis, Plumularia spiralis*).

Hydroids in Baa Atoll displayed large populations in several sites, while in others they were less abundant but diversified as well. When in large populations, the largest species were one of the main components of the underwater landscape (see Plates). These large species with ten to thirty centimeter-long erected colonies mainly belong to leptothecates, and to the family Aglaopheniidae, especially *Gymnangium*, *Lytocarpia* and *Macrorhynchia* species. They usually sheltered diversified sessile and vagile microflora and microfauna, with other hydroid species either obligatorily associated or not.

CONCLUSION AND PERSPECTIVES

The present extensive study of hydrozoan communities in Baa Atoll provides new data that improve the state of knowledge of marine biodiversity of Indian Ocean countries, recently reviewed by Wafar et al. (2011). It yielded a significant increase in known hydroid species richness for the Maldives Archipelago (x2.5), with 100 species recorded for the first time, and the first estimation specific to Baa Atoll. However, 44% of the coral reef habitats of Baa Atoll were not sampled (Andréfouët et al., 2010 and this issue) like for example the bottom of the lagoon and many reef flats. Thus, the estimates provided here are conservative. Further investigations are warranted to complete exhaustively the census of hydroids for Baa and the Maldives, and to assess if missing taxa like *Millepora* are susceptible to come back. Regionally, the Baa census provided fresh new results that confirm previous knowledge, but also pose biogeographic questions in terms of presence/absence of species otherwise absent or dominant in the region.

Many specimens of the collection have not yet been fully identified. Lack of reproductive structures on specimens and need for additional taxonomic studies for several genera prevented the complete identification of all samples. Besides this collection, 300 additional samples were conserved in alcohol for further genetic studies. Genetic data have recently assisted in taxonomic studies of hydrozoans (for example Schuchert, 2005; Miglietta et al., 2007 & 2009; Miranda et al, 2010; Moura et al., 2011 & 2012). They could address several taxonomic problems encountered during the present study, especially to compare sterile specimens with fertile ones, and to separate closely related species.

ACKNOWLEDGMENTS

The authors want to acknowledge Serge Andréfouët and Shiham Adam, PIs of the project funded by the French “Fondation pour la Recherche sur la Biodiversité” (FRB) and the Atoll Ecosystem Conservation project (AEC). We are grateful to Allen Collins who improved the English and provided well-advised remarks, to Hélène Magalon and Bautisse Postaire for the statistical tests, to Michel Pichon and Carlo Nike Bianchi for sending literature on Maldives coral reef studies, Steve Cairns for confirmation of stylasterid data, and Charles Anderson and Alain Diringer for data on book marine fauna. Many thanks for Jean-Louis Menou and Claude Payri who provided samples, and to Olivier Dumont who created the plates (Appendix 3). Our gratitude is expressed towards both the Marine Research Center of the Maldives (MRC) for scientific collaboration during the field survey, and especially to Yoosuf Rilwan for diving support and sampling assistance and to Shafiya Naeem for the laboratory work, and to the NOAH boat team for their hospitality.

REFERENCES

Including those concerning Appendix 1 here below (annotated list of species)

Agassiz, A.
1903. An expedition to the Maldives. *American Journal of Sciences*, Ser. 4, 76: 297-308.
Anderson, R.C.
1991. Living reefs in the Maldives. Novelty Press, Malé. 100pp.
Andréfouët S., Hamel M., and Y. Rilwan.
2010. Planning marine protected areas on Baa atoll (Republic of Maldives). *Technical report IRD, MRC, University of Reunion Island, AEC, UNDP,* 18 pp.
Andréfouët S., Rilwan, Y., and M. Hamel.
2012. Habitat mapping for conservation planning in Baa Atoll, Republic of Maldives. *Atoll Research Bulletin* 590: 207-221.
Bianchi, C.N., Morri, C., Colantoni, P., and M. Sandrini.
2009. Italian research in the Maldives. *Reef Encounter*, 37: 17.

Bianchi, C.N., Morri, C., Pichon, M., Benzoni, F., Colantoni, P., Baldelli, G., and M. Sandrini.

2006. Dynamics and pattern of coral recolonization following the 1998 bleaching event in the reefs of the Maldives. *Proceedings of the 10th International Coral Reef Symposium*, Okinawa, Japon, 1: 30-37.

Bigelow, H.B.

1904. Medusae from the Maldive Islands. *Bulletin of the Museum of Comparative Zoology* 39: 244-269, pl. 1-9.

Billard, A.

1913. Les Hydroïdes de l'expédition du Siboga. I Plumulariidae. *Siboga Expeditie* 7a: 1-115, pls 1-6.

Billard, A.

1925. Les Hydroïdes de l'expédition du "Siboga".II. Synthecidae et Sertularidae. *Siboga-Expeditie* 7b: 117-232.

Boone, L.

1938. Scientific Results of the World Cruises of the yachts "Ara," 1928-1929, and "Alva," 1931-1932, "Alva" Mediterranean Cruise, 1933, and "Alva" South American Cruise, 1935. Part II Coelenterata. *Bulletin of the Vanderbilt Marine Museum*, 7: 28-45, pl. 4-6.

Borradaile, L.A.

1905. Hydroids. *The fauna and geography of the Maldive and Laccadive Archipelagoes* 2: 836-845, pl. 69.

Boschma, H.

1948. The species problem in *Millepora*. *Zoologische Verhandelingen* 1: 1-115, pl. 1-15.

Bouillon, J., Wouters, K., and F. Boero.

1992. Etude des Solanderiidae de la Baie de Hansa (Papouasie Nouvelle-Guinée) avec une révision du genre *Solanderia*. *Bulletin de l'Institut royal des Sciences naturelles de Belgique, Biologie* 62: 5-33.

Bouillon, J., Gravili, C., Pagès, F., Gili, J-M., and F. Boero.

2006. An introduction to Hydrozoa. *Mémoires du Muséum National d'Histoire Naturelle Paris* 194: 1-591.

Bourmaud, C.A-F., Leung, J.K.L., Bollard, S., and N. Gravier-Bonnet.

Mass spawning events, seasonality and reproductive features in Milleporids (Cnidaria, Hydrozoa) from Reunion Island (Indian Ocean): first studies. *Marine Ecology*, submitted.

Bourmaud, C.A-F., Leclère, L., Mangion, P., Michonneau, F., and G. Pennober.

2006. Biodiversity of Réunion coral reefs. *Proceedings of the 10th International Coral Reef Symposium*, Okinawa, Japon, 1: 202-207.

Broch, H.

1947. Stylasteridae (Hydrocorals) of the Jonh Murray expedition to the Indian Ocean. *John Murray Expedition 1933-34, Scientific reports* 8(2): 305-316, pl.1.

Browne, E.T.

1904. Hydromedusae, with a Revision of the Williadae and Petasidae. *The fauna and geography of the Maldive and Laccadive Archipelagoes* 2: 722-749, pl. 54-57.

Calder, D.

1991. Shallow-water hydroids of Bermuda: the Thecatae, exclusive of Plumularioidea. *Life Sciences Contributions* 154: 1-140.

Calder, D.

2010. Some anthoathecate hydroids and limnopolyps (Cnidaria, Hydrozoa) from the Hawaiian archipelago. *Zootaxa* 2590: 1-91.

Coleman, N.

2000. *Marine life of the Maldives*. (French translation 2004)

Di Camillo, C.G., Bavestrello, G., Valisando, L., and S. Puce.

2008. Spatial and temporal distribution in a tropical hydroid assemblage. *Journal of the Marine Biological Association of the United Kingdom* 88: 1589-1599.

Gardiner, J.S.

1904. *The fauna and geography of the Maldive and Laccadive Archipelagoes.*

Glynn, P. W., and J. S. Feingold.

1992. Hydrocoral species not extinct. *Science* 257: 1845.

Glynn, P. W., and W. H. Weerdt.

1991. Elimination of two reef-building hydrocorals following the 1982-83 El Nino warming event. *Science* 253: 69-71.

Gravier, N.

1970. Etude des Hydraires épiphytes des Phanérogames marines de la région de Tuléar (Sud-Ouest de Madagascar). *Recueil des Travaux de la Station marine d'Endoume, Fasc. hors série*, suppl. 10: 111-161.

Gravier-Bonnet, N.

2008. The hydranth of *Salacia tetracythara* Lamouroux, 1816 (Cnidaria, Hydrozoa, Sertulariidae) and its modified tentacles. *Journal of the Marine Biological Association of the United Kingdom* 88: 1723-1729.

Gravier-Bonnet N., and C.A-F. Bourmaud.

2005. Cloning by releasing specialized frustules in a successful epiphytic zooxanthellate halecid (Cnidaria, Hydrozoa, Haleciidae), with comments on stolonization and frustulation. *Journal of Invertebrate Reproduction and Development* 48: 63-69.

Gravier-Bonnet, N., and & C.A-F. Bourmaud.

2006a. Hydroids (Cnidaria, Hydrozoa) of coral reefs: preliminary results on community structure, species distribution and reproductive biology in Juan de Nova island (Southwest Indian Ocean). *Western Indian Ocean Journal of Marine Science,* 5(2): 123-132.

Gravier-Bonnet N., and C.A-F. Bourmaud.

2006b. Hydroids (Cnidaria, Hydrozoa) of coral reefs: preliminary results on community structure, species distribution and reproductive biology in the Îles Glorieuses (Southwest Indian Ocean). *Proceedings of the 10th International Coral Reef Symposium,* Okinawa, Japon 1: 188-196.

Gravier-Bonnet, N., and D. Mioche.

1996. Annual survey of hydroids (Cnidaria, Hydrozoa) cohabiting into shrimp-crevices on a reef flat of La Réunion (Indian Ocean). *Scientia Marina* 60: 165-181.

Jimenez, H., Bigot, L., Bourmaud, C., Chabanet, P., Gravier-Bonnet, N., Hamel, M., Payri, C., Mattio, L., Menou, J.L., Naeem, S., Rilwan, Y., Sattar, S., Scott, L., Shiham, A., Vigliola, L., and S. Andréfouët.
Multi-taxa coral reef community structure in relation to habitats in the Baa Atoll Man and Biosphere UNESCO Reserve (Maldives), and implication for its conservation. *Journal of Sea Research* (submitted).

Lewis, J.B.
2006. Biology and Ecology of the Hydrocoral *Millepora* on Coral Reefs. *Advances in Marine Biology* 50: 1-55.

Mammen, T.A.
1965. On a collection of Hydroids from South India. III Family Plumulariidae. *Journal of the Marine Biological Assocociation of India* 7: 291-324.

Mayer, A.G.
1910. *Medusae of the world. The Hydromedusae Vol 1*. Publication of the Carnegie Institute of Washington 109: 1-230.

McClanahan, T.R.
2000. Bleaching damage and recovery potential of Maldivian coral reefs. *Marine Pollution Bulletin* 40(7): 587-597.

Miglietta, M.P., Piraino, S., Kubota, S., and P. Schuchert.
2007. Species in the genus *Turritopsis* (Cnidaria, Hydrozoa): a molecular evaluation. *Journal of Zoological Systematics and Evolutionary Research* 45: 11-19.

Miglietta, M.P., Schuchert, P., and C. Cunningham.
2009. Reconciling genealogical and morphological species in a worldwide study of the Family Hydractiniidae (Cnidaria, Hydrozoa). *Zoologica Scripta* 38: 403-430.

Migotto, A.E., and A.S. Cabral.
2005. *Lafoeina amirantensis* (Cnidaria: Hydrozoa, Campanulinoidea), the hydroid stage of the medusa *Cirrholovenia tetranema* (Cnidaria: Hydrozoa, Lovenelloidea). *Zootaxa* 919: 1-16.

Miranda, L.S., Collins A.G., and A.C. Marques.
2010. Molecules clarify a cnidarian life cycle – The "hydrozoan" *Microhydrula limopsicola* is an early life stage of the staurozoan *Haliclystus antarcticus*. *PLoS ONE* 5(4): e10182. doi:10.1371/journal.pone.0010182.

Morri, C., Bianchi C.N., and S. Aliani.
1995. Coral reefs at Gangehi (North Ari atoll, Maldive Islands). *Publications du Service géologique du Luxembourg* 29: 3-12.

Moura, C.J., Cunha, M.R., Porteiro, F.M., and A.D. Rogers.
2011. The use of the DNA barcode gene 16S mRNA for the clarification of taxonomy problems within the family Sertulariidae (Cnidaria, Hydrozoa). *Zoologica Scripta*, 40, 520-537.

Moura, C.J., Cunha, M.R., Porteiro, F.M., Yesson, C., and A.D. Rogers.
2012. Evolution of marine hydroids of the genus *Nemertesia* (Cnidaria: Hydrozoa, Plumulariidae) from the shallow and deep NE Atlantic and W Mediterranean. *Zoologica Scripta* (in press).

Oliveira, O.M.P., and A.C. Marques.
2007. Epiphytic hydroids (Hydrozoa: Anthoathecata and Leptothecata) of the World. *Check List* 3: 21-38.

Pichon, M.
1978. Recherches sur les peuplements à dominance d'anthozoaires dans les récifs coralliens de Tuléar (Madagascar). *Atoll Research Bulletin* 222: 1-447.

Rees W.J., and W. Vervoort.
1987. Hydroids from the John Murray Expedition to the Indian Ocean, with revisory notes on *Hydrodendron*, *Abietinella*, *Cryptolaria* and *Zygophylax* (Cnidaria: Hydrozoa). *Zoologische Verhandelingen*, *Leiden* 237: 1-209.

Scheer, G., and K. Obrist.
1986. *Distichopora nitida* Verrill (Cnidaria, Hydrozoa) from the Maldives, a new record from the Indian Ocean. *Coral Reefs* 5: 151-154.

Schuchert, P.
2003. Hydroids (Cnidaria, Hydrozoa) of the Danish expedition to the Kei Islands. *Steenstrupia* 27(2): 137-256.

Schuchert, P.
2004. Revision of the European athecate hydroids and their medusae (Hydrozoa, Cnidaria): families Oceanidae and Pachycordylidae. *Revue Suisse de Zoologie* 111: 315-369.

Schuchert, P.
2005. Species boundaries in the hydrozoan genus *Coryne*. *Molecular Phylogenetics and Evolution* 36: 194-199.

Stoddart, D.R.
1966. Reef studies at Addu Atoll, Maldive Islands: preliminary results of an expedition to Addu Atoll in 1964. *Atoll Research Bulletin* 116: 1-122.

Vervoort, W.
1993. Report on hydroids (Hydrozoa, Cnidaria) in the collection of the Zoological Museum, University of Tel-Aviv, Israel. *Zoologische Mededelingen*, *Leiden* 67: 537-565..

Vervoort, W., and P. Vasseur.
1977. Hydroids from french Polynesia with notes on distribution and ecology. *Zoologische Verhandelingen*, *Leiden* 159: 1-98.

Wafar, M., Venkataraman, K., Ingole, B., Ajmal Khan, S., and P. LokaBharathi.
2011. State of Knowledge of Coastal and Marine Biodiversity of Indian Ocean Countries. *PLoS ONE* 6(1): e14613. doi:10.1371/journal.pone.0014613.

Watson, J.E.
2000. Hydroids (Hydrozoa: Leptothecatae) from the Beagle Gulf and Darwin Harbour, northern Australia. *The Beagle, Records of the Museums and Art Galleries of the Northern Territory* 16: 1-82.

Wells, J.W., and P.S. Davies.
1966. Preliminary list of stony corals from Addu atoll. *Atoll Research Bulletin* 116: 43-55.

Wilkinson C., Linden, O., Cesar, H., Hodgson, G., Rubens, J., and A.E. Strong.
1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? *Ambio* 28(2): 188-196.

Appendix 1.

Annotated checklist of the species collected in Baa Atoll during the 2009 survey.

Families inside sub-orders and genera inside families arranged in alphabetical order and classification according to Peter Schuchert (2009) World Hydrozoan database available online at http://www.marinespecies.org/hydrozoa.
✷ Species photographed in Appendix 3. ♦ Species already reported in the Maldives Archipelago, sometimes under another name (15spp).

ANTHOATHECATA Cornelius, 1992

FILIFERA Kühn, 1913

Bougainvilliidae Lütken, 1850

Bimeria vestita Wright, 1859

Two sterile colonies collected at the same station, stolonal and growing on stems of other hydroids. Pseudo-hydrotheca and base of tentacles embedded by particulate matter. Hydranth very tiny, with 9-10 tentacles, the top of which only is visible.

Eudendriidae L. Agassiz, 1862

Species were separated during the field trip mainly on shape and color of living colonies.

Eudendrium racemosum (Cavolini, 1785) ✷ ♦

The largest and most frequent *Eudendrium* species in Baa Atoll. Branched colony brown, not in a plane, with large hydranths and gonophores orange. Characteristic nematophores were present only on some hydranths. We suspect that *Eudendrium maldivense* described by Borradaile (1905, pl. 69, fig. 1) is a synonym of *E. racemosum*. The general shape of the colony and male gonophores are similar but, however, Borradaile did not notice any nematophore on hydranths. On our material, such nematophores were rare. They could have been even more rare on Borradaile colony as about all the hydranths bear male gonophores on their body in the same place as nematophores.

Eudendrium sp. 1
Eudendrium sp. 2
Eudendrium sp. 3
Eudendrium sp. 4
Eudendrium sp. 5
Eudendrium sp. 6

Colonies of this bright red species were encountered twice. It could be a new species.

Oceaniidae Eschscholtz 1829

Cordylophora sp.

Sterile colony partly stolonal, with several erected sympodial stems (0,8 cm) bearing only two to four hydranths. Tubes of hydranths free on most of their length, but some having a very short part like nested. Hydranths spindle shaped bearing about 25 scattered tentacles, orange in life.

Corydendrium corrugatum Nutting, 1905

The presence of an anterior and rear side for the colony is typical of *C. corrugatum* according to Schuchert (2003), and distinguishes it from *Corydendrium parasiticum*. We collected sterile colonies having this character, small ones twice (2 cm, of which one with stolonal hydranths on the stem of *Gymnangium hornelli*), and one large (7 cm) tree-liked, fasciculate, branching with a large angle (about 90°), branches clearly having two different faces and a hand shape. Tubes supporting hydranths of large diameter, adnate on most of their length and directed on one side, with corrugations not well marked on the free part. Large hydranths provided with 40-50 tentacles, tissues and hydranths bright yellow for the largest colonies. Differences in tentacle number and color for the small colonies (respectively orange and white) raise questions.

Corydendrium sp.

Sterile colonies collected in a plane (3 cm), both fasciculated and ramified, with no obvious difference from ventral versus dorsal face. Free part of tubes short to very short, thus hydranths being about adnate to the stem. Very large hydranths provided with up to 30 tentacles, light orange or transparent. Rees & Vervoort (1987) reported *Corydendrium parasiticum* (Linnaeus) from 37 m deep near the Maldives islands by (04° 50’ 18” - 04° 53’ 00” N, 72° 52’ 48” - 72° 55’ 24” E), but our specimens exhibit a different colony shape. As the few other *Corydendrium* species described have very different geographical distribution, this one could belong to a new species.

Rhizogeton sp.

Colony stolonal, hydranth base covered by a short collar of skeleton. Hydranths elongated with scattered tentacles on the whole body. Most often the polyps exhibit characteristic small white dots at the tentacle base. This species is widely distributed in the Indian Ocean (description in progress).

Turritopsis chevalense (Thornely, 1904) ✷

Specimens from Baa agree with the original description of the polyp stage of this little known species of which the medusa is unknown. Moreover, *T. chevalense* was described from the Indian Ocean, while *Turritopsis nutricula* McCrady, 1857 is an Atlantic species (Schuchert, 2004; Miglietta et al, 2007). Schuchert (2003) noticed “the *Turritopsis* species of the tropical Indo-Pacific might all be referable to *T. chevalense* described from Ceylon, but that they are at present not distinguishable from other *Turritopsis* hydroids”. In waiting the genetic study of the Baa samples, we keep together colonies that differ in the color of hydranths and tissues (white or bright yellow), general shape (more in a plane or more bushy), and number of hydranth tentacles (from 15 to 30), and thus that could include multiple species. Observed several times, medusa buds were inserted, as described by Thornely, along the free part of the tubes, below the hydranths, with different developmental stages at the same time, except in one instance where they were both all sited at the same level on a circle around the tube and at about the same age. New-borne medusae are provided with 4 radial canals, 8 tentacles, and embryonic gonads as 4 pads (yellow on some) on the median part of the manubrium. Tentacles exhibit a typical posture directed to the apex of the umbrella and enroll on themselves while swimming. Bigelow (1904) reported one unidentified *Turritopsis* sp. medusa collected in a tow at Felidu Atoll.

Turritopsis sp.

Two tiny colonies collected (0.5 cm), mainly stolonal. The larger one with a few erected stems monosiphonic, bearing few hydranths, tubes with a free part forming an angle of about 45° with the stem. A single medusa bud was growing on tube just below hydranth. Hydranths with 15 tentacles, white when alive. For the general shape of the colony and stolonal hydranths, this species looks like *Corydendrium album* Hirohito, 1988, but the gonophore here is, without any doubt, a medusa. As no similar species was found in the recent reviews done on the genus *Turritopsis* (Schuchert, 2004; Miglietta et al, 2007) this species is probably a new species. More fertile material and the rearing of the medusa could provide better data and correlations with some species known from fully-grown medusae only.

Pachycordylidae Cockerel, 1911

?Pachycordyle sp.

A few hydranths on a sterile colony settled on *Thyroscyphus fruticosus*, reported once.

Proboscidactylidae Hand & Hendrickson, 1950

?Proboscidactyla sp.

A sterile colony on the operculum of a Polychete, with few hydranths looking like *Proboscidactyla* hydranths but having 4 tentacles instead of 2, probably a new species which will require modification of the diagnosis of the genus. *Proboscidactyla varians* was a new species described by Browne (1904) from a single medusa collected at Miladumadulu Atoll. Later considered as probably an abnormal specimen of *Proboscidactyla ornata* by Mayer (1910), this species was excluded from a recent catalogue (Bouillon et al., 2006).

Stylasteridae Gray, 1847

Distichopora violacea (Pallas, 1766) ✷ ♦

Usually common in Indian Ocean coral reefs, colonies of *D. violacea* were rarely observed in Baa Atoll and found at only four stations. It was however already previously recorded in the Maldives archipelago (Coleman, 2000). On the color plates below, the small colony of *Distichopora* photographed near *Stylaster roseus* (but not collected) could be either a orange colored colony of *D. violacea*, a species variable in color, or another species, *Distichopora nitida* Verrill 1864, that has thinner branches and was previously reported from the Maldives by Scheer & Obrist (1986), and probably also by Coleman (2000) as *Distichopora* sp.

Stylaster roseus (Pallas, 1766) ✷

As for *D. violacea*, *S. roseus* was a rare species in Baa (reported in only three stations).

CAPITATA Kühn, 1913

Cladocorynidae Allman, 1872

Cladocoryne haddoni Kirkpatrick, 1890

Corynidae Johnston, 1936
Coryne nipponica (Uchida, 1927)

Milleporidae Fleming, 1828
Millepora ?platyphylla Hemprich & Ehrenberg, 1834 ✷ ♦

The general shape of the single colony encountered during this study is not typical for shape and color (see color plates), but it looks like other colonies that we sampled in the Comoros Archipelago. Genetic studies are now in progress to study varied growth morphs of *M. platyphylla* in the Indian Ocean where we suspect the presence of cryptic species. The typical growth morph of *M. platyphylla* is that photographed in Coleman (2000). According to Boschma (1948), *M. platyphylla* was recorded in the Maldives Islands "under the name *Millepora complanata,* first by Darwin (1842) and then by Sewell (1936)" from Horsburgh or Goifurfehendu Atoll.

Pennariidae McCrady, 1859
Pennaria disticha Goldfuss, 1820 ✷ ♦

Previously checked by Coleman (2000).

Sphaerocorynidae Prévot, 1959
Sphaerocoryne bedoti Pictet, 1893

Tubulariidae Fleming, 1828
Ectopleura viridis (Pictet, 1893) ✷ ♦

Previously checked in the Maldives as *Tubularia pacifica* (Thornely, 1900) by Borradaile in 1905 (recent literature: Schuchert, 2003; Calder, 2010). Hydranth up to 1.5 cm with pedicel, bottom rounded, a circle of 25 long tentacles at base and 12 shorter around the mouth, bunches of medusa buds between the two circles. Medusa buds with two tentacles.

Tubulariidae indet.

Hydranths with pedicels up to 0,6 cm, with 12-13 long tentacles at base and 7 very short around the mouth having nematocysts concentrated at top (pseudo-capitations), gonophores very young settled in between, either isolated or in bunches of three according to the hydranths. Because of its smaller size, thinner and shorter tentacles, and hydranths not rounded at base, this is probably a different species than *E. viridis* and not juveniles hydranths. It was not identified because of immature gonophores.

Zancleidae Russell, 1953
Zanclea sp.1

Associated with hard corals. Hydranths transparent provided with numerous capitate tentacles, small medusa buds growing on long pedicels.

Zanclea sp. 2

Associated with bryozoans. Hydranths transparent, except for the white hypostome, equipped with 5 oral tentacles with large capitations, tentacles on the body both shorter and with a smaller diameter of capitations.

Zanclea sp. 3

Associated with bryozoans. Hydranths transparent except for white hypostome and dots inside the capitations of tentacles, 6 long oral tentacles with large capitations and others long tentacles on the body provided with smaller capitations.

Zanclea sp. 4

Species not associated with other sessile animals, but conversely growing on other substrata. Hydranths entirely transparent, provided with 6 long oral tentacles and about 30 tentacles on the body, whose length shortens gradually towards base.

Capitata indet.

On a Bryozoan, tentacle-like hydranths transparent very tiny, immerged in the colony substratum after fixation.

LEPTOTHECATA Cornelius, 1992

CONICA Broch, 1910

Aequoridae Eschscholtz, 1829

Aequorea sp.

A single sterile colony was collected, however confirming the presence of the genus. A fragmentary specimen of a medusa of *Aequorea coerulescens* (Brandt, 1838), a Pacific species, was reported by Bigelow (1904) from the Maldives, but said to be “insufficient for positive identification” by Boone (1938). *Aequorea maldivensis* Browne, 1904, was described as a new species from three specimens collected in Haddumati Atoll, but was later considered a synonym of *Aequorea macrodactyla* by Mayer (1910).

Aglaopheniidae Marktanner-Turneretscher, 1890

Aglaophenia postdentata Billard, 1913

The *Aglaophenia gracillima* described as a new species by Borradaile (1905) from some sterile fragments dredged at 50 meters deep in Miladumadulu Atoll is very close to the specimens of *A. postdentata* we collected in shallow waters in Baa during this study. They both have the same shape and characters for hydrotheca and nematothecae, but on *A. gracillima* the impair adcauline tooth of the hydrothecal aperture is absent (9 teeth instead of 10) and the articles on hydrocladiae are longer. *Aglaophenia gracillima* Borradaile, 1905 is not listed in Bouillon et al (2006). It differs strongly from *Aglaophenia gracillima* Fewkes, 1881, a species described earlier and probably unknown to Borradaile who created a homonym. A revision of Borradaile’s collection and more material from the Maldives is necessary to decide if his *A. gracillima* is a valid species and eventually give it a new name.

Gymnangium ?eximium (Allman, 1874) ✷

The colonies provisionally so identified are not provided with a lateral tooth at the orifice of the hydrotheca as described in the literature, and observed previously on specimens from the Indian Ocean (Mammen, 1965; Rees & Vervoort, 1987). They are closer to specimens from the Pacific (French Polynesia) described with a “blunt” lateral tooth, so blunt that it is about invisible on the drawings (Vervoort &

Vasseur, 1977, p. 82, fig. 34). In the absence of a lateral tooth on Baa specimens of *G. ?eximium*, the hydrothecae of this species are very close to that of *G. gracilicaule* but their colonies differ in color (yellow green/white), general shape (strictly in a plane/not), consistency (sturdy/slender) and ramifications (motionless/mobile around a basal hinge joint) (see plates in Appendix 3), and the gonothecae also are different, though all flat. Genetic studies are in progress on these related species.

Gymnangium gracilicaule (Jäderholm, 1903) ✷

See the brief comparative description in *G. ?eximium.*

Gymnangium ?gracilicaule (Jäderholm, 1903)

Two specimens have been kept separately in respect of the absence of hinge joint at the base of the branches and of the presence of longer hydrothecae than in the typical form.

Gymnangium hians (Busk, 1852) ✷

We suspect several cryptic species to be included in the specimens identified as *G. hians* in Baa, as in other parts of the world. Genetic sub-samples will probably permit to solve this problem.

Gymnangium hornelli (Thornely, 1904) ✷

Whereas this species has an hydrotheca of a shape very similar to those of *G. ?eximium* and *G. gracilicaule*, though slightly longer, the colonies are different from both. The main character that differentiates this species is the presence on the stems and branches of modified hydrocladiae all along enrolled around, provided of nematothecae only, and very fragile, thus falling down easily on fixed material. Moreover, the colonies are not in a plane, and the branches are spirally inserted around the stem and connected by a shorter hinge joint than for *G. gracilicaule* (see plates in Appendix 3).

Lytocarpia brevirostris (Busk, 1852) ✷ ♦

Previously reported from the Maldives (Hulule, Male Atoll) by Borradaile (1905) as *Aglaophenia maldivensis* n. sp., a species put in synonymy by Billard (1913) according to the description and drawing given by Borradaile, and though the presence of hydrothecae on corbula costae was not checked.

Lytocarpia delicatula (Busk, 1852) ✷ ♦

Previously reported from the Maldives (S Nilandu) by Borradaile (1905), and a photograph of this flexuous feather like species is in the chapter "The Hydrozoans" of the book of Anderson (1991, p. 57).

Lytocarpia phyteuma (Kirchenpauer, 1876) ✷

Macrorhynchia philippina Kirchenpauer, 1872 ✷ ♦

Previously checked by Coleman (2000). As for *G. hians*, we suspect several cryptic species under this name in the Indian Ocean (genetic studies in progress).

Macrorhynchia ?philippina Kirchenpauer, 1872

A single specimen that could be a juvenile form of *M. philippina* or a close species.

Macrorhynchia phoenicea (Busk, 1852) ✷ ♦

Previously reported from the Maldives by Borradaile (1905) from Male, Addu, S Nilandu and Malhos Atolls, and by Morri et al (1995) from Ari Atoll. Under this name we have gathered numerous specimen that could have been separated in groups for weak differences and that will be further compared genetically.

Macrorhynchia singularis (Billard, 1908) ✷

This is a rare species originally described from New Guinea and recently reported in Indonesia (Schuchert, 2003). This is the second record for the Indian Ocean, as previously reported in Madagascar (Tuléar) by Pichon (1978) and identified by N. Gravier-Bonnet.

Macrorhynchia spectabilis (Allman, 1883) ✷ ♦

A photograph in the chapter "The Hydrozoans" of the book of Anderson (1991, p. 57) is probably *M. spectabilis*.

Campanulinidae Hincks, 1868

Campanulinidae indet.

Cirrholoveniidae Bouillon, 1984

Cirrholovenia tetranema Kramp, 1959 = *Lafoeina amirantensis* (Millard and Bouillon, 1973)

This species was originally called *Egmundella amirantensis* by the authors and then transferred to the genus *Lafoeina* by Calder (1991). Recently, Migotto & Cabral (2005) studied its life cycle and discovered that it is the polyp phase of the medusa *Cirrholovenia tetranema* Kramp, 1959. As the medusa was described first, the species must be spelled according to the medusa name.

Haleciidae Hincks, 1868

Halecium sp. 1
Halecium sp. 2
Halecium sp. 3
Halecium sp. 4
Halecium sp. 5
Halecium sp. 6
Hydrodendron gardineri (Jarvis, 1922)
Hydrodendron sp.

The single sterile and stolonal colony collected was growing on *Dynamena crisioides* and had the type shape that characterized previously the genus *Ophiodissa* nowadays in synonymy with *Hydrodendron*.

Nemalecium lighti (Hargitt, 1924) ✷

Large branched photophilic colonies of a white color, found on varied substrata.

Nemalecium sp. 1

This species, close to *N. lighti* but smaller and of a bright white-blue color, is very common in Indian Ocean shallow waters. Previously reported as *N. lighti*, some of its biological and ecological traits have already been published (Gravier-Bonnet & Mioche, 1996). The morphological description of the two new species (*Nemalecium* sp. 1 and sp. 2), together with the result of the genetic study of the *Nemalecium* group, will be published separately.

Nemalecium sp. 2

Halopterididae Millard, 1962

Antennella incerta Galea, 2010

Antennella secundaria (Gmelin, 1791)

Antennella sp. 1

Stems rigid, obviously and regularly segmented by alternate oblique and straight joints. Hydrothecae short and regular, with convex abcauline wall only sometimes slightly curved just under the aperture. Lateral nematotheca short but inserted on a long peduncle, never reaching the hydrothecal aperture, with upper chamber very wide. Tissues and hydranths bright yellow.

Antennella sp. 2

Very large and high hydrotheca with a slightly convex abcauline wall not at all curved below aperture and a very long straight adcauline wall. Lateral nematothecae inserted on long pedicel, long and tubular, with upper chamber glass-shaped with even orifice and only slightly enlarging from base to top, growing much over the aperture of the hydrotheca. A median impair nematotheca is present above the hydrotheca. Hydrothecae of a similar shape and provided with long lateral nematothecae are considered as variations of the variable species *Antennella secundaria* by Schuchert (1997). As we did not observe in our Baa specimens any intermediary form between *A. secundaria* and *Antennella* sp. 2, we consider this last as a new species to be described.

Halopteris platygonotheca Schuchert, 1997

Living specimens of this large species have stems evenly colored in light green. Female gonothecae are very large and flattened but contain a single big oocyte.

Halopteris sp. 1

Halopteris sp. 2

Halopteris sp. 3

Halopteris sp. 4

Halopteris sp. 5

Monostaechas quadridens (MacCrady, 1859)

Hebellidae Fraser, 1912

Hebella furax Millard, 1957

Hebella laterocaudata Billard, 1942

Hebella muscensis Millard & Bouillon, 1975

Hebella scandens (Bale, 1888) ♦

Already recorded by Borradaile (1905) as *Lictorella scandens.*

Hebella sp.

Lafoeidae A. Agassiz, 1865

Filellum sp.

Zygophylax rufa Bale, 1884 ✷ ♦

Colony growing in a plane, with skeleton colored in red both on stems and branches. Some colonies almost deprived of nematothecae. From two Maldives atolls (Northern Malé and Goifurfehendu), Borradaile (1905) reported *Lictorella halecioides* Allman, though he described differences between his material and Allman's one, which seems to be *Zygophylax rufa*. He also made a large mistake in describing the gonotheca for the first time whereas it is, without any doubt, the hydrotheca of an epizootic *Hebella* species. Coleman (2000) also reported a *Zygophylax* sp.

Plumulariidae McCrady 1859

Plumularia group *setacea* (Linnée, 1758)

This group that includes related species distributed worldwide is now in revision by Peter Schuchert.

Plumularia spiralis Billard, 1911 ✷

Plumularia strictocarpa Pictet, 1893

Plumularia sp.

This species is related to *Plumularia badia* Kirchenpauer, 1876, but the branching is very different and probably indicates that this *Plumularia* is a new species.

Sertulariidae Lamouroux, 1812

Dynamena moluccana (Pictet, 1893) ✷

Dynamena cornicina McCrady, 1859

Dynamena crisioides Lamouroux, 1824 ✷ ♦

In Baa Atoll, this species was found in two forms: the classical described by Lamouroux and one longer, named var. *gigantea* by Billard in 1925. We agree with Billard (1925) who signaled that the new species described by Borradaile (1905) as *Synthecium maldivense* is without any doubt *D. crisioides gigantea* for its coral reef habitat and the disposition of hydrothecae.

Dynamena sp. 1

Dynamena sp. 2

Idiellana pristis (Lamouroux, 1816) ♦

This species has been previously recorded in the Maldives, in Suvadiva and Male Atolls (Borradaile, 1905).

Salacia desmoides (Torrey, 1902)

Salacia tetracythara Lamouroux, 1816

Sertularella delicata Billard, 1919 ✷

The characters allowing to distinguish easily this species from *Sertularella diaphana* (Allman, 1886) are its peculiar lace growing more or less in a plane, and its bright yellow color. *S. diaphana* develops large erected colonies with polysiphonic stems giving rise to branches in three dimensions like a tree, and is of a salmon-pink color.

Sertularella robusta Coughtrey, 1876

Colony simple, hydrothecae long and narrowing at orifice, with corrugations and a single empty gonotheca with corrugations in the upper part and a neck provided with very obtuse teeth.

Sertularella sp. 1

Specimens related to that of *S. robusta* for colony and hydrotheca shapes, but with either no corrugations on hydrotheca or only inconspicuous ones on adcauline side, and with large corrugated female gonothecae narrowing at the aperture but without a true neck and teeth. Planulae were developing in an acrocyst, about ten in each. These specimens have been kept provisionally separated from *S. robusta* for different shape of the gonotheca and because of the lack of corrugations on the hydrotheca. However, colony and hydrotheca shapes being similar, it could be a sexual dimorphism that we can't verify as the single gonotheca of *S. robusta* we recovered is empty.

Sertularella sp. 2

Colony simple, with hydrothecae about quadrate having smooth walls and provided with 4 internal teeth.

Sertularia distans (Lamouroux, 1816)

This species was found settled on a bit of leave of a marine Phanerogam (*Thalassia*) thrown on the boat deck.

Sertularia maldivensis (Borradaile, 1905) ♦

Originally described by Borradaile as *Thuiaria maldivensis*. Schuchert (2003) regards this species as possibly a synonym of *Sertularia borneensis* Billard, 1925. Hydrothecae, on the single colony collected, are closed to those figured by Borradaile, and differ from that of *S. borneensis* in having the length of the adnate part about equal or shorter than the free. Fertile specimen is needed to go further in identification. This is the second record for the Maldives as it was previously collected at Suvadiva Atoll (Borradaile, 1905).

Sertularia sp.

Syntheciidae Marktanner-Turneretscher, 1890

Recent literature on the genus *Synthecium* (Watson, 2000; Schuchert, 2003) demonstrated how difficult is the identification of species, even with fertile specimens. This is the case for three related species, *Synthecium patulum* (Busk, 1852), *Synthecium orthogonium* (Busk, 1852), and *Synthecium campylocarpum* Allman, 1888. Two of the four Baa species belong to this group and are here tentatively identified, pending more data and genetic studies.

Synthecium flabellum Hargitt, 1924 ✷

Large colonies of a dark brown, nearly black, provided with gonothecae, classical in shape.

Synthecium ?orthogonium (Busk, 1852) ✷

Small colonies of a deep dark red, provided with gonothecae elongated and flattened, with corrugations, rounded on top or sometimes with a very short narrowing below the orifice.

Synthecium patulum (Busk, 1852) ✷

Colonies uncolored, with long saussage shape male gonothecae with 8-9 strong corrugations, female also corrugated but shorter and rounded. Baa specimens are provisionally attributed to *S. patulum* because it is clearly related to that of Billard (1925). However, Watson (2000) and Schuchert (2003) think that Billard's specimens of *S. patulum* have to be put in synonymy with *Synthecium orthogonium*.

Synthecium sp.

Small colonies absolutely black, provided with large hydrothecae about half adnate on the hydrocladium and half free. Specimens collected at 50 meters, without gonophores.

Thyroscyphidae Stechow, 1920
Thyroscyphus fruticosus (Esper, 1793) ✷ ♦

Described from the Maldives as a new species by Borradaile (1905), *Campanularia junceoides* is probably a synonym of *T. fruticosus*.

PROBOSCOIDA Broch, 1910

Campanulariidae Johnston, 1836
Campanularia sp. 1
Campanularia sp. 2
Campanularia sp. 3
Clytia hummelincki (Leloup, 1935)
Clytia gracilis (M. Sars, 1850)
Clytia latitheca Millard & Bouillon, 1973
Clytia linearis (Thornely, 1900) ✷
Clytia sp. 1
Clytia sp. 2
Clytia sp. 3
Clytia sp. 4
Obelia dichotoma (Linnaeus, 1758)

Leptothecata indet. sp. 1
Leptothecata indet. sp. 2
Leptothecata indet. sp. 3

Appendix 2. Species distribution among stations in Baa Atoll.

Genera	*species* / stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28
Aequorea	sp.				1																		
Aglaophenia	*postdentata*												1			1							
Antennella	*incerta*	1							1														
Antennella	*secundaria*	1			1			1	1									1				1	
Antennella	sp. 1										1		1										
Antennella	sp. 2																		1				
Antennella	indet.			1																		1	
Bimeria	*vestita*																		1				
Campanularia	sp. 1								1														
Campanularia	sp. 2																					1	
Campanularia	sp. 3										1												
Campanularide	indet									1													
Campanulinide	indet													1									
Capitata	indet	1																					
Cladocoryne	*haddoni*											1										1	
Clytia	*gracilis*				1	1	1	1							1					1			
Clytia	*hummelincki*																1			1			1
Clytia	*latitheca*	1		1				1							1								
Clytia	*linearis*	1			1		1	1			1	1		1	1	1				1	1	1	
Clytia	sp. 1					1																	
Clytia	sp. 2							1															
Clytia	sp. 3										1												
Clytia	sp. 4					1																	
Clytia	indet.	1		1	1	1	1	1		1	1	1	1	1			1	1	1			1	
Cordylophora	sp.	1																					
Corydendrium	*corrugatum*					1								1									

Appendix 2 (Con’td)

Genera	*species* / stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28
Corydendrium	sp.							1												1			
Coryne	*nipponica*												1										
Distichopora	*violacea*	1															1	1			1		
Dynamena	*cornicina*				1				1														
Dynamena	*crisioides*			1		1	1	1			1		1	1		1	1	1		1	1	1	
Dynamena	*moluccana*			1			1	1		1	1	1	1		1					1	1	1	1
Dynamena	sp. 1															1							
Dynamena	sp. 2												1										
Ectopleura	*viridis*										1										1		
Eudendrium	*racemosum*	1			1							1		1	1	1	1			1			
Eudendrium	sp. 1	1									1												
Eudendrium	sp. 2	1			1	1		1	1		1	1		1	1								
Eudendrium	sp. 3	1			1	1																	
Eudendrium	sp. 4				1																		
Eudendrium	sp. 5						1	1		1		1											
Eudendrium	sp. 6																			1		1	
Eudendrium	indet.												1								1	1	
Filellum	sp.				1		1	1				1						1				1	
Gymnangium	*?eximium*							1			1	1			1					1		1	
Gymnangium	*hians*			1		1	1	1	1	1	1	1			1			1		1	1	1	
Gymnangium	*hornelli*					1											1						
Gymnangium	*gracilicaule*				1											1							
Gymnangium	*?gracilicaule*	1						1															
Halecium	sp. 1	1																					
Halecium	sp. 2			1	1			1															
Halecium	sp. 3			1																			
Halecium	sp. 4				1																		

Appendix 2 (Con’td)

Genera	*species* / stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28
Halecium	sp. 5																	1					
Halecium	sp. 6										1		1										
Halecium	indet.							1															
Halopteris	*platygonotheca*										1	1			1	1	1	1					
Halopteris	sp. 1	1		1		1						1			1		1			1			1
Halopteris	sp. 2	1		1		1		1			1												
Halopteris	sp. 3				1			1				1											
Halopteris	sp. 4					1	1				1												
Halopteris	sp. 5										1												
Halopteris	indet.										1			1	1	1		1		1		1	1
Hebella	*furax*											1	1	1									
Hebella	*laterocaudata*														1								
Hebella	*muscensis*				1			1							1								
Hebella	*scandens*							1	1	1	1		1							1			
Hebella	sp.	1								1												1	
Hydraire	indet.			1																			
Hydrodendron	*gardineri*							1															
Hydrodendron	sp.							1															
Idiellana	*pristis*				1																		
Lafoeina	*amirantensis*																				1		
Leptothecate	indet.				1	1			1					1	1								
Lytocarpia	*brevirostris*	1						1		1		1		1	1			1				1	
Lytocarpia	*delicatula*													1									
Lytocarpia	*phyteuma*				1			1		1						1		1				1	
Macrorhynchia	*spectabilis*										1	1		1	1	1	1		1			1	
Macrorhynchia	*singularis*					1																	
Macrorhynchia	*philippina*						1							1		1					1		

Appendix 2 (Con’td)

Genera	*species* / stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28
Macrorhynchia	*?philippina*									1													
Macrorhynchia	*phoenicea*									1	1	1	1	1	1	1							
Macrorhynchia	indet.											1											
Millepora	*?platyphylla*													1									
Monostaechas	*quadridens*							1														1	
Nemalecium	*lighti*					1	1				1	1			1	1	1	1		1			1
Nemalecium	sp. 1	1		1		1	1	1	1		1	1		1	1		1	1				1	1
Nemalecium	sp. 2			1																			
Obelia	*dichotoma*					1																	
?Pachycordyle	sp.														1								
Pennaria	*disticha*	1		1	1	1	1	1						1	1	1				1	1		
Plumularia	*spiralis*						1							1	1	1	1				1		
Plumularia	group *setacea*	1			1						1		1	1						1		1	
Plumularia	*strictocarpa*					1			1														
Plumularia	sp.						1									1				1			
Plumularide	indet.									1													
?Proboscidactyla	sp.														1								
Rhizogeton	sp.	1		1									1				1						1
Salacia	*desmoides*								1														
Salacia	*tetracythara*							1															
Sertularella	*delicata*			1	1	1	1	1	1	1		1		1	1	1	1	1		1	1		1
Sertularella	*robusta*	1								1												1	
Sertularella	sp. 1											1											
Sertularella	sp. 2								1														
Sertularia	*maldivensis*												1										
Sertularia	sp.																						1
Sphaerocoryne	*bedoti*													1									

Appendix 2 (Con'td)

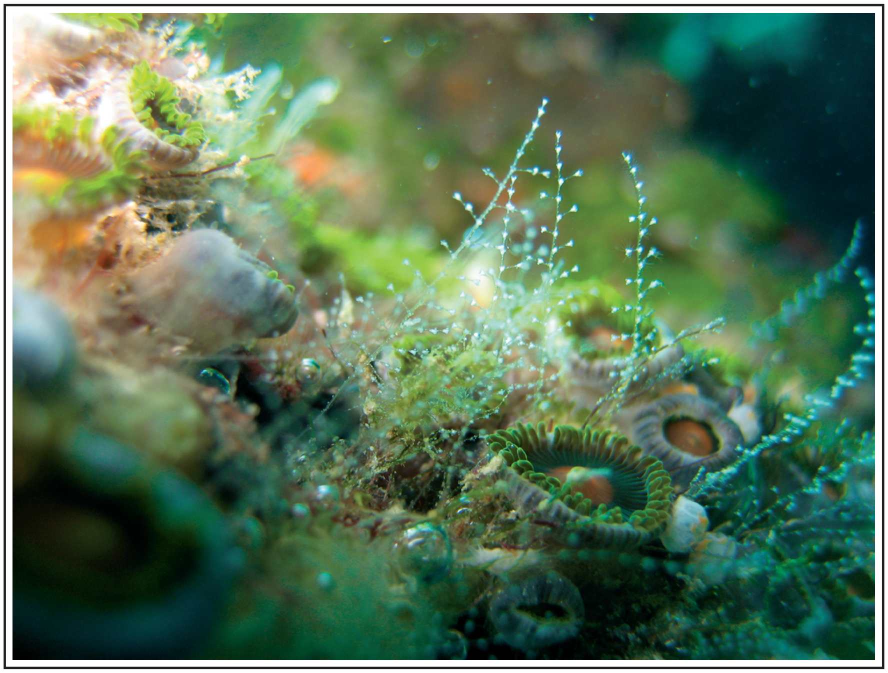
Genera	*species* / stations	1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	23	24	25	27	28
Stylaster	*roseus*																	1		1	1		
Synthecium	*?orthogonium*				1		1	1			1												
Synthecium	*flabellum*						1							1									
Synthecium	*patulum*			1	1	1		1	1		1		1	1	1	1		1	1			1	
Synthecium	sp.																		1				
Thyroscyphus	*fruticosus*				1	1	1	1		1	1	1		1	1	1	1			1	1	1	1
Tubularide	indet											1			1								
Turritopsis	*chevalense*	1								1	1	1		1		1				1			
Turritopsis	sp.				1	1																	
Zanclea	sp. 1	1		1		1										1							
Zanclea	sp. 2				1	1																	
Zanclea	sp. 3																	1					
Zanclea	sp. 4											1											
Zygophylax	*rufa*									1		1		1						1		1	
Total	(121 records*)	25	0	18	27	26	19	33	14	17	28	27	16	27	27	21	15	17	6	22	14	25	10

* Six of the unidentified records listed above need additional taxonomic studies to be assigned to the species listed in Appendix 1.

Appendix 3. Plates with in situ and underwater photographs.

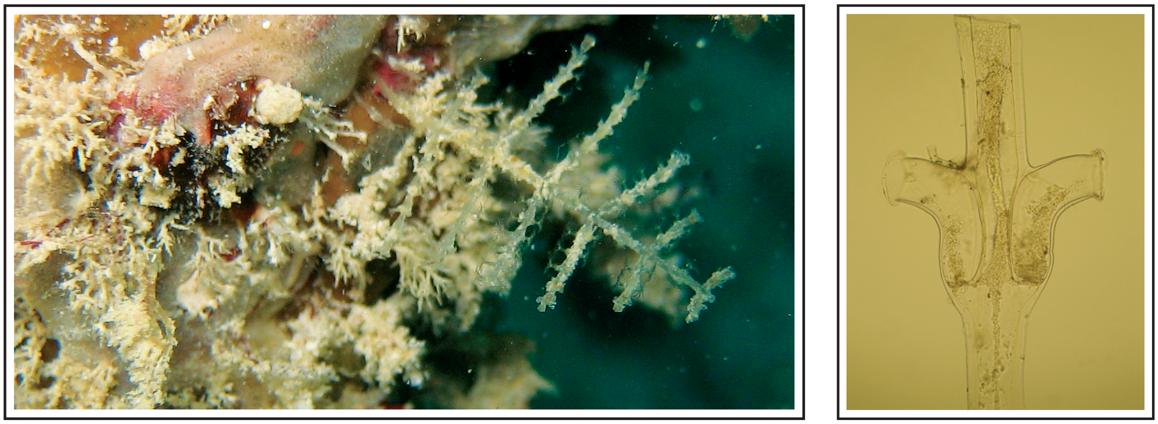
Underwater Baa atoll landscapes with hydroids at different scales

Plumes of *Lytocarpia brevirostris* among other sessile organisms

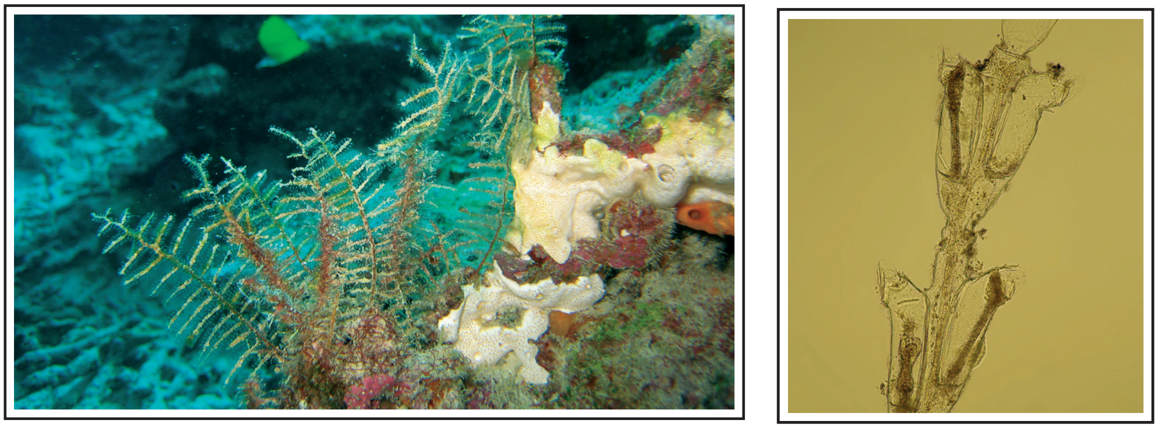


Turf of *Halopteris* sp. among small actinians

Leptothecates: protected polyps retractable into skeletal chambers (hydrothecae) provided or not with an operculum

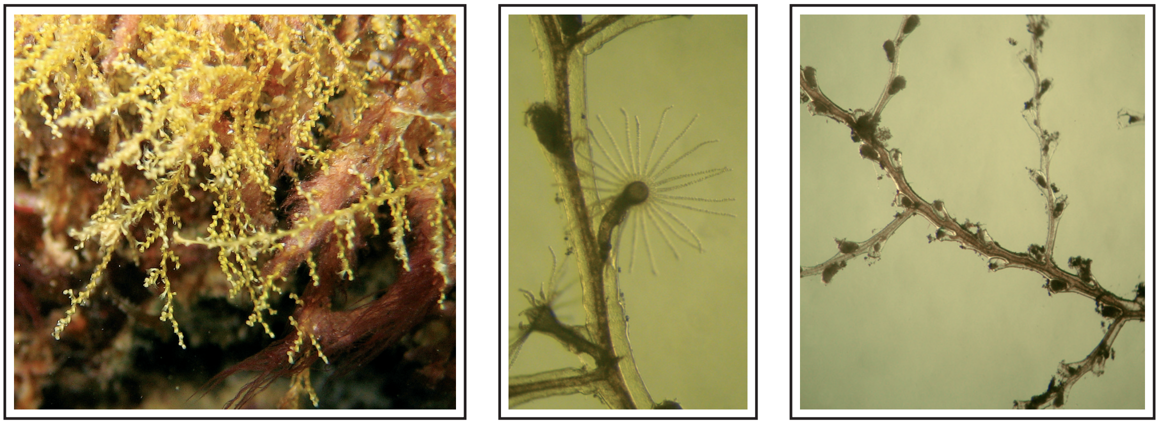


Synthecium patulum (Syntheciidae) has the characteristic opposite branches of the family with un-operculated hydrothecae in pairs. Its tissues are colorless conversely to other species (see below).

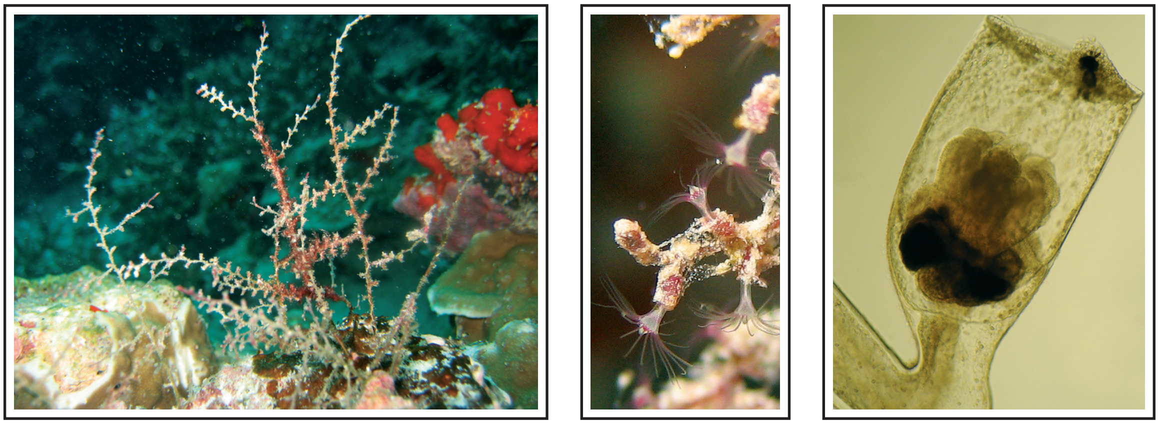


Dynamena crisioides (Sertulariidae) forms either small or large colonies in a plane (up to 4 or 10 cm for var. *gigantea* like here), the zig-zag shape of the stem being only visible on the top for larges. Its light yellow color can be hidden by particulate matter and organisms settled on the skeleton.

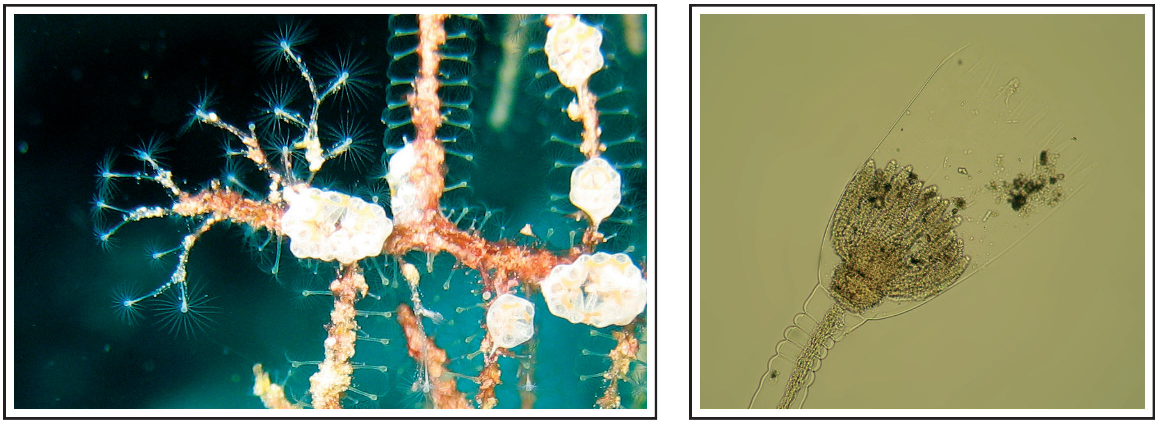
Dynamena moluccana (Sertulariidae) forms yellow pinnate and flexuous colonies that have been encountered in about each dive in Baa. Under currents, contrary of most of the sertularid species (see *D. crisioides*), branches are characteristically able to pivot on themselves (see varied positions here).



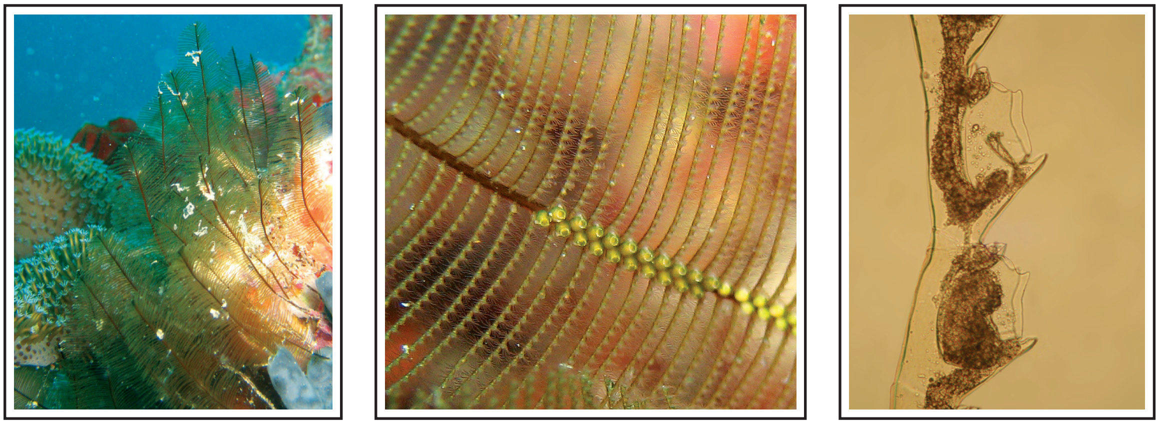
Sertularella delicata (Sertulariidae) exhibit typical bright yellow lace colonies. Large polyps inhabit short hydrothecae alternating on the branches, and closed by a four valves operculum. A circle of filiform tentacles surrounds the polyp mouth.



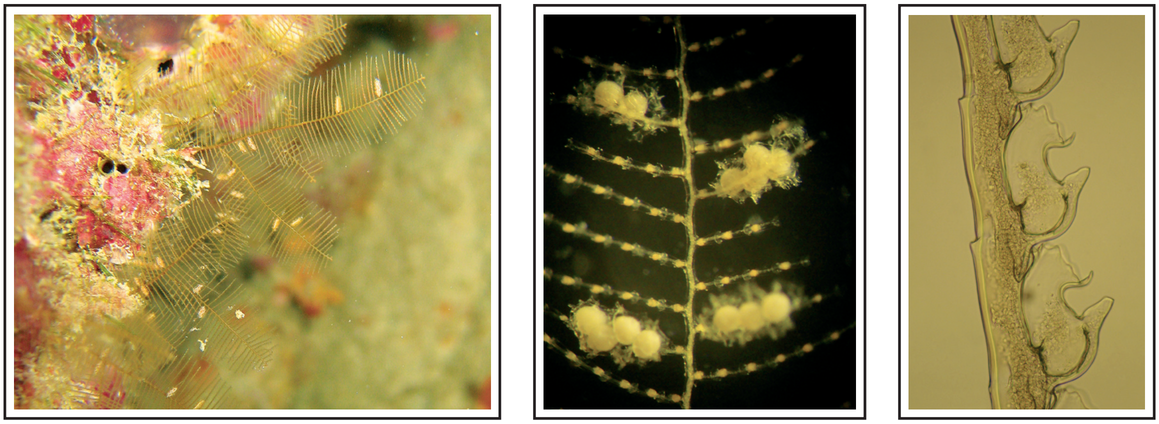
Thyroscyphus fruticosus (Thyroscyphidae) characterizes tropical intertidal and shallow waters of the Indian Ocean coral reefs. It is easy to recognize with its bright pink color associated to large pedunculated hydrothecae. The transparent skeleton takes usually a pink color as well, due to encrusting calcareous algae all around its surface.



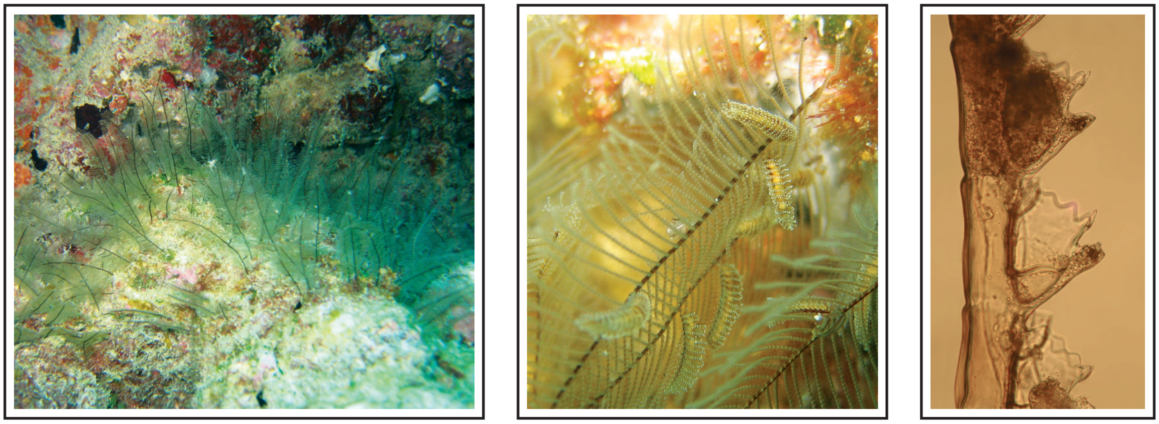
Clytia linearis (Campanulariidae) is a branched species with white polyps, settled here on the top of *D. crisioides* colonized by red cyanophytes and compound ascidians. This ubiquitous species was found on varied substrata and depths. Longitudinal lines visible at the surface of the hydrotheca gave it its name, whereas the margin teeth are not easily seen.



Gymnangium hians (Aglaopheniidae) exhibits feather-shaped rigid and thick colonies variable in color (green to brown), and grows in clumps. Hydrothecae have no operculum and are arranged unilaterally in files along the hydrocladial tube, like for all species of the family. Hydrothecae are shared by an intrathecal septum underneath the polyp retracts. See rounded reproductive features on the stem (gonothecae).

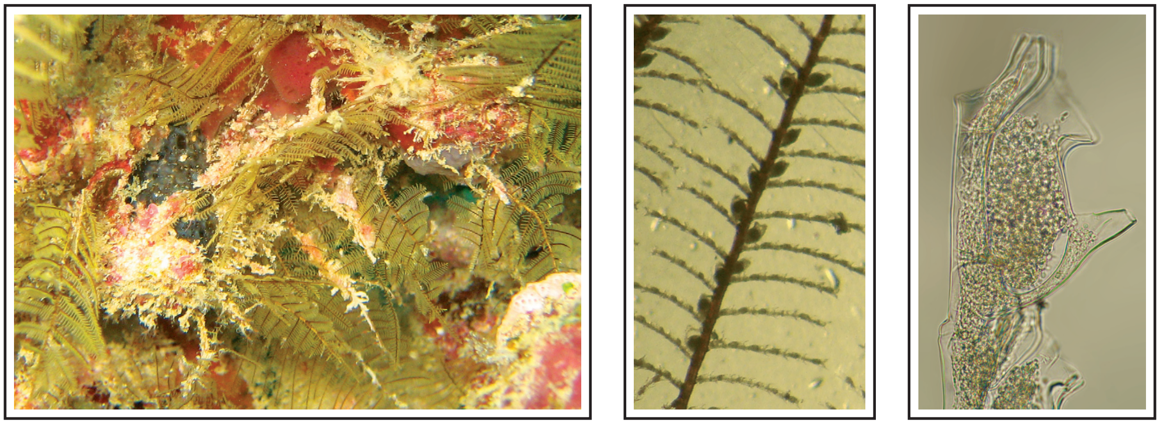


Lytocarpia brevirostris (Aglaopheniidae) has graceful pinnate colonies strictly in a plane, with an uniform light brown-orange color. When fertile, like in the pictures, they bear small oval reproductive features (corbulae) where larvae are brooded. The hydrothecae are curved with an aperture lined by lateral teeth plus one median.

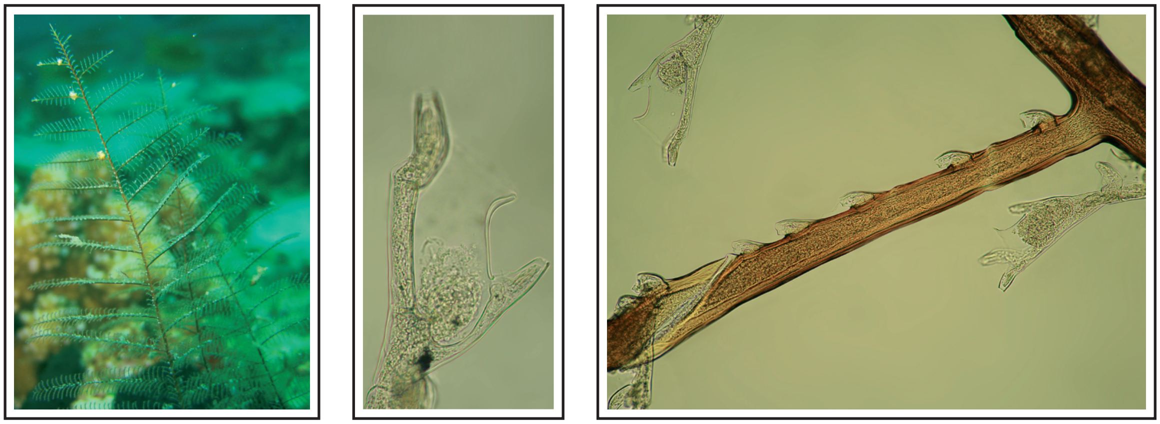


Lytocarpia phyteuma (Aglaopheniidae) is feather-shaped. It exhibits very long corbulae when fertile. Hydrocladiae are clear in color whereas the thick stem is often striated of brown and beige. The hydrotheca has regular lateral teeth plus one median, and a lateral skeletal thickening that seems to separate it in two chambers.

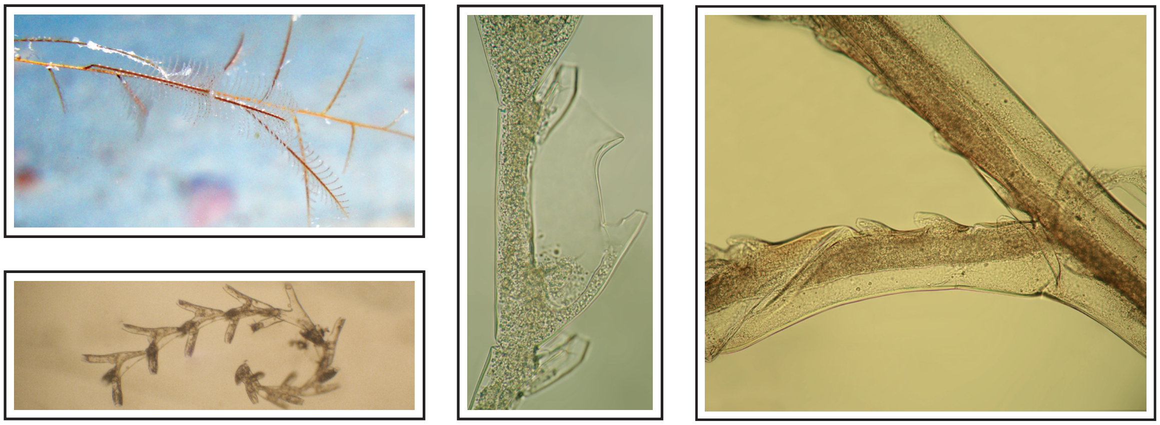
Other Baa atoll macroscopic hydroid species of the Aglaopheniidae family



Gymnangium eximium forms colonies with stem and branches strictly in a plane. Its color is yellow-green except for brown stems and branches. The even aperture and the shape of the hydrotheca are very similar to *G. gracilicaule* and *G. hornelli* below, but a small thickening of the skeleton is present at the curving.

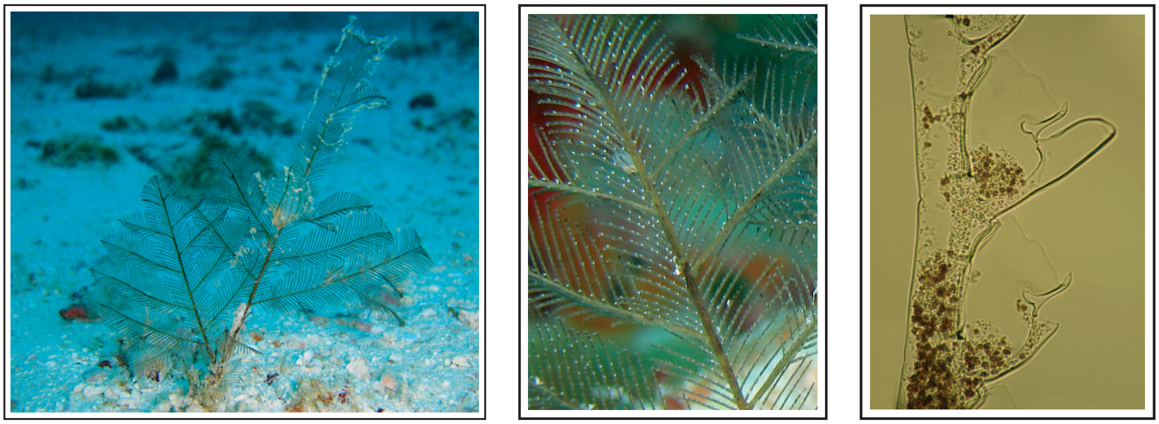


Gymnangium gracilicaule exhibits slender colonies in a plane. Branches are connected with the stem by a long apophysis that ends by an oblique joint. As a consequence, they take a characteristic position, perpendicular to the plane of the colony, by rotating around the joint like for *D. moluccana* hydrocladiae.



Gymnangium hornelli shows long and flexuous colonies with branches inserted in a spiral (not in a plane) and delicate modified hydrocladiae (with nematothecae) surrounding the stem, a feature that allows identification. It has a strong oblique joint on a shorter apophysis than *G. gracilicaule*, and more elongated hydrothecae.

Macrorhynchia philippina is a stinging species having large and very flexuous colonies that branch up to three times. Inside the hydrotheca, the septum, linked to a small median tooth, appears triangular in profile view, not like a plate as in *M. phoenicea*. There is only one low lateral tooth on each side of the aperture.

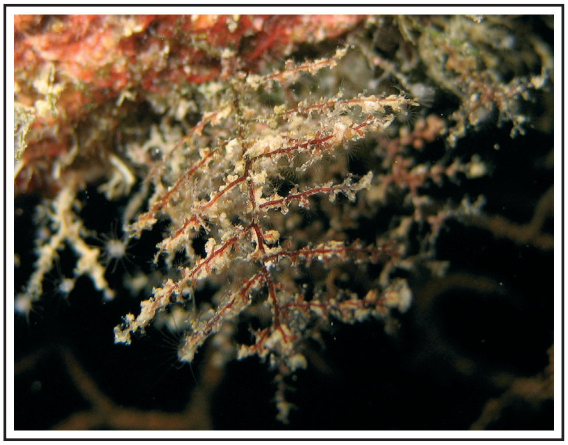


Macrorhynchia singularis colonies are ramified in a plane and entirely brown, with a lot of characteristic white dots related to one big median nematotheca encountered besides some hydrothecae, a microscopic character allowing species identification.

Other Baa atoll macroscopic hydroid species

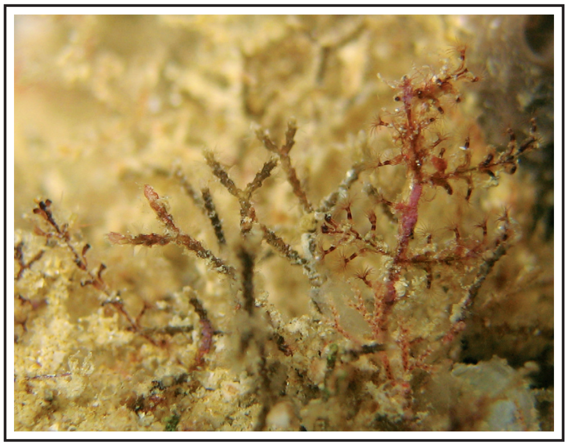
Anthoathecates (rare species)

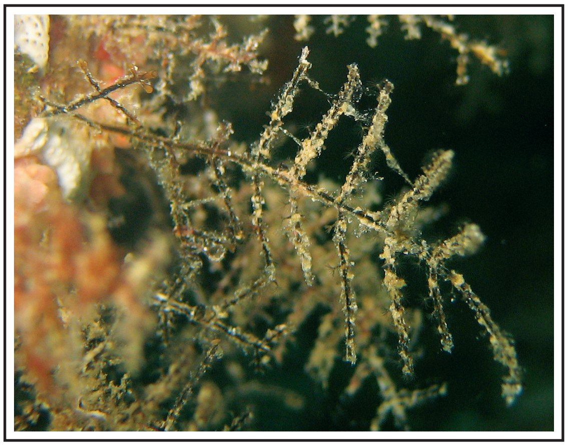
Turritopsis chevalense (Oceaniidae) grows in clumps of large polyps bearing scattered filiform tentacles on the body column and exhibiting varied colors (white, yellow). This species reproduces by the means of medusae.



Nemalecium lighti (Haleciidae) is common species on coral reefs, forming nice colonies with bright white-blue flexuous polyps able to bend in all directions.

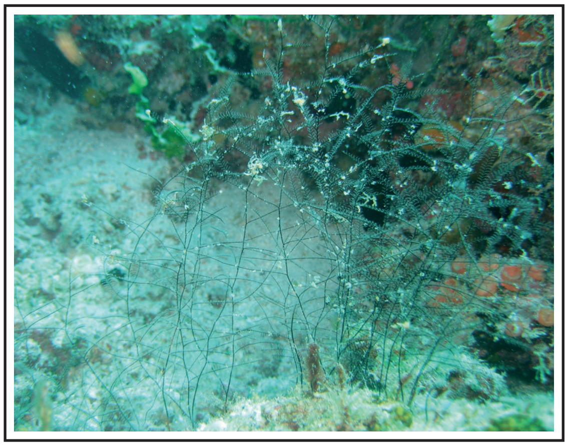
Zygophylax rufa (Lafoeidae) is characterized by its dark red rigid colonies in a plane, with sub-opposite branches. Particulate matter usually covers the skeleton.





Synthecium ?orthogonium (Syntheciidae) differs of the two other Synthecium species notably by its dark red color. Notice expanded hydranths on right and the branched bryozoan in the center.

Synthecium flabellum (Syntheciidae) develops large colonies strictly in a plane with opposite branches. The living tissues are very dark, about black.



Plumularia spiralis (Plumulariidae) is strongly recognizable from its black thin stems and branches of equal diameter, and from the spirally branching of the colony.

MACRO-INVERTEBRATE COMMUNITIES OF BAA ATOLL, REPUBLIC OF MALDIVES

BY

SERGE ANDRÉFOUËT,[1] JEAN-LOUIS MENOU,[1] AND SHAFIYA NAEEM[2]

ABSTRACT

In order to guide conservation efforts in Baa Atoll in the Republic of Maldives, macro-invertebrate species (principally sponges, sea stars, urchins, holothurians, crinoids, ophiuroids, ascidians, bivalves, gastropods, anemones, zooanthids, anthipatharian, gorgonians, alcyonaceans, and flatworms) were inventoried on 21 sites to provide an index of benthic species richness (number of species). A total of 182 species were recorded and identified. Richness ranged between 6 to 40 species per sampling sites. The richest sites were hard-bottom submerged lagoonal patch reefs experiencing high currents. Ecological rarity dominates the macro-invertebrate community pattern with 95 species found in only one sampling site. This new data set brings fresh knowledge on Baa Atoll and Maldives in order to identify biodiversity hot-spots. Further work will investigate the sensitivity of biodiversity conservation planning and sitting algorithms to this data set.

INTRODUCTION

Invertebrates include an extremely wide range of organisms with 8 major phyla (Porifera, Cnidaria, Annelida, Sipuncula, Arthropoda, Mollusca, Echinodermata, Chordata), and 24 minor phyla (see Glynn and Enochs, (2011) for a complete list). Coral reefs offer the richest biodiversity on Earth, along with tropical rainforest (Reaka-Kudla, 1997), and the greatest part of this diversity lies in the invertebrate communities. Glynn and Enochs (2011) recently reviewed the taxonomy and functional roles of invertebrates in coral reefs. They offer a synoptic view of the complexity of the invertebrate world. Here, we will consider more particularly the macro-invertebrates. The definition of the macro-invertebrate community is fuzzy, and context-dependant. For instance, Glynn and Enochs (2011) distinguished for cryptic species the macrofauna from the meiofauna, depending if the specimen body size is larger than 1 mm or not. Thus, body sizes, associated with investigation means and habitats define in a relative way the community of macro-invertebrates. Here, the macro-invertebrate benthic community includes all species that can be detected by eye while diving or snorkeling, on soft to hard-bottoms, on both biotic and abiotic substrates.

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Trying to measure invertebrate biodiversity for any given reef complex such as a Maldivian atoll is a daunting challenge that requires enormous field work efforts (Bouchet et al., 2011), rare taxonomic expertise, and genetic analyses. Thus, coral reef sites compendium providing within an accepted taxonomic reference the full range of existing species for most of the 32 phyla are extremely rare (e.g., New-Caledonia in Payri and Richer de Forges, 2006; Guam in Paulay 2003, Santo Island, Vanuatu in Bouchet et al. 2011).

Among valuable resources, a number of specialized taxonomic publications list macro-invertebrate species for selected phyla and locations (e.g., for New Caledonia: echinoderms, ascidians, sponges, gorgonians, are described respectively in Guille et al. 1986, Moniot et al., 1991; Levi et al. 1998; Grasshoff and Bargibant, 2001) but no recent taxonomic compilation exists for Maldives macro-invertebrates to our knowledge. The previous reference was Clarke and Rowe (1971) which is now outdated for several species.

Several well illustrated field guide books list invertebrates species for a given region (e.g., Colin and Arneson, 1995; Coleman, 2001; Laboute and Richer de Forges, 2004; Hervé, 2010; Poupin and Juncker, 2010). Web-based databases and information systems are also increasingly set to catalogue and identify species, and infer distribution maps (e.g., the integrated Taxonomic Information System, http://www.itis.gov, the World Register of Marine Species http://www.marinespecies.org/index.php, the Ocean Biogeographic Information System, http://v2.iobis.org/ and its Indian Ocean node http://www.indobis.org/). Nevertheless, to measure and characterize the biodiversity of a particular previously undocumented coral reef site, often, only a limited number of phyla (e.g., Cnidaria), classes (e.g., Anthozoa), orders (e.g;, Scleractinia) are targeted for new collections. Even more often, in a conservation or monitoring context, census and characterization focus only on few indicator species from various phyla, typically commercial and functionally prominent species of mollusk, crustaceans and echinoderms. This limited approach, taxonomically speaking, corresponds to rapid assessments as performed for instance by NGOs (e.g., Conservation International, McKenna et al., 2009; The Nature Conservancy, Ramohia, 2006), although some taxa have been more thoroughly investigated (e.g., mollusks in McKenna et al., 2002, Appendix 3).

To provide a measurement of Baa Atoll invertebrate biodiversity as completed as possible given the logistic and expertise constraints, it was decided to provide for the most dominant atoll habitats a list of conspicuous macro benthic invertebrates found during day time only. The rationale is that this macro-fauna assessment would provide an index of biodiversity to characterize reef habitat benthic richness and to guide the identification of biodiversity hot-spots for conservation planning (Hamel and Andréfouët, this issue). We report here on the variation of this richness in Baa Atoll. Therefore, the invertebrate sampling effort performed in Baa Atoll can not be compared to huge efforts such as those conducted recently in Santo Island for instance (Bouchet et al., 2011), but it provides an enhanced view of Baa Atoll communities richer than most typical rapid assessment programs that focussed on commercial species only (Le Berre et al., 2009). The Baa census included scleractinian (hard corals) and hydrozoans. These taxa are treated elsewhere (Bigot and Hamir, this issue; Gravier-Bonnet and Bourmaud, this issue). The present census did not consider crustaceans for time and logistical reasons.

METHODOLOGY

Macro-invertebrates communities were sampled during day dives conducted between 26 May to 4 June 2009. During each dive, specimen were inventoried from the deeper areas (typically around 40 m) to the shallows following a random path. This technique is generally more rewarding for biodiversity census than working through transects and quadrats that limit the searching spatial domain. Specimens were photographed in situ, and brought on board the diving vessel for further examination and identification when needed. Specimen were identified at the highest possible taxonomic level (species or genera). No museum collections were created.

Sampling sites were selected to cover the dominant reef types and exposure in Baa Atoll. This included outer oceanic slope and flats, submerged lagoon patch reefs, and sheltered central lagoonal slopes and reef flats. A total of 21 sites were sampled across Baa Atoll (Fig. 1).

Richness per station was simply defined as the number of species, all phyla included, found during the survey.

RESULTS AND DISCUSSION

The survey of the 21 stations provided a total of 182 identified species (Table 1 in Appendix), plus 5 specimen of sponges and 2 Crinoidea species left unidentified. Records were distributed among the phylum Cnidaria (class Anthozoa, n=34), Echinodermata (class Asteroida n=10, Crinoidea n=9, Echinoidea n=7, Holothuroidea n=12, Ophiuroidea n=11), Mollusca (class Bivalvia n=14, Cephalopoda n=1 and Gastropoda n=48), Porifera (class Calcarea n=3, Demospongiae n=26) ,Chordata (class Ascidiacea,n=7), Annelida (class Polychaeta, n=1) and Platyhelminthes (class Turbellaria, n=1). Selected specimen are illustrated Plates 1 to 5.

Richness per station ranged between 6 (station 23: deep lagoon, and station 2: seagrass bed) to 40 species (station 1, lagoon slope and reef flat). Figure 2 and Figure 3 provide the continuum of richness found for all stations. In terms of richness per habitat, the submerged lagoon patch reef frequently provided high richness (*N*>29) with stations 10, 11, 17, 25. These stations were characterized by high currents, hard-bottom and numerous hang-outs and small caves. Station 19, one of the poorest stations with 12 species, was also a patch reef characterized by high current but also by soft bottom, in contrast with the richer patch reef sites.

Average richness per geomorphological habitat type varied (Fig. 4), but the poorest habitats (deep lagoon, oceanic reef flat, and seagrass beds) where also the less sampled (n=1 for each of them). For the well sampled habitats (n>5), richness appeared homogeneous without significant difference (Fig. 4). The survey that occurred only on lagoon reef flats (thus without adjacent deep slopes) yielded a similar richness (*N*=26, n=1, station 3) than the dives that occurred on both lagoon slopes and flats (*N*=23.5, n=7), even if they have been visited only once. Thus, a sampling effort bias on lagoon reef flats was likely less an issue to estimate richness, compared to deep lagoons and outer reef flats.

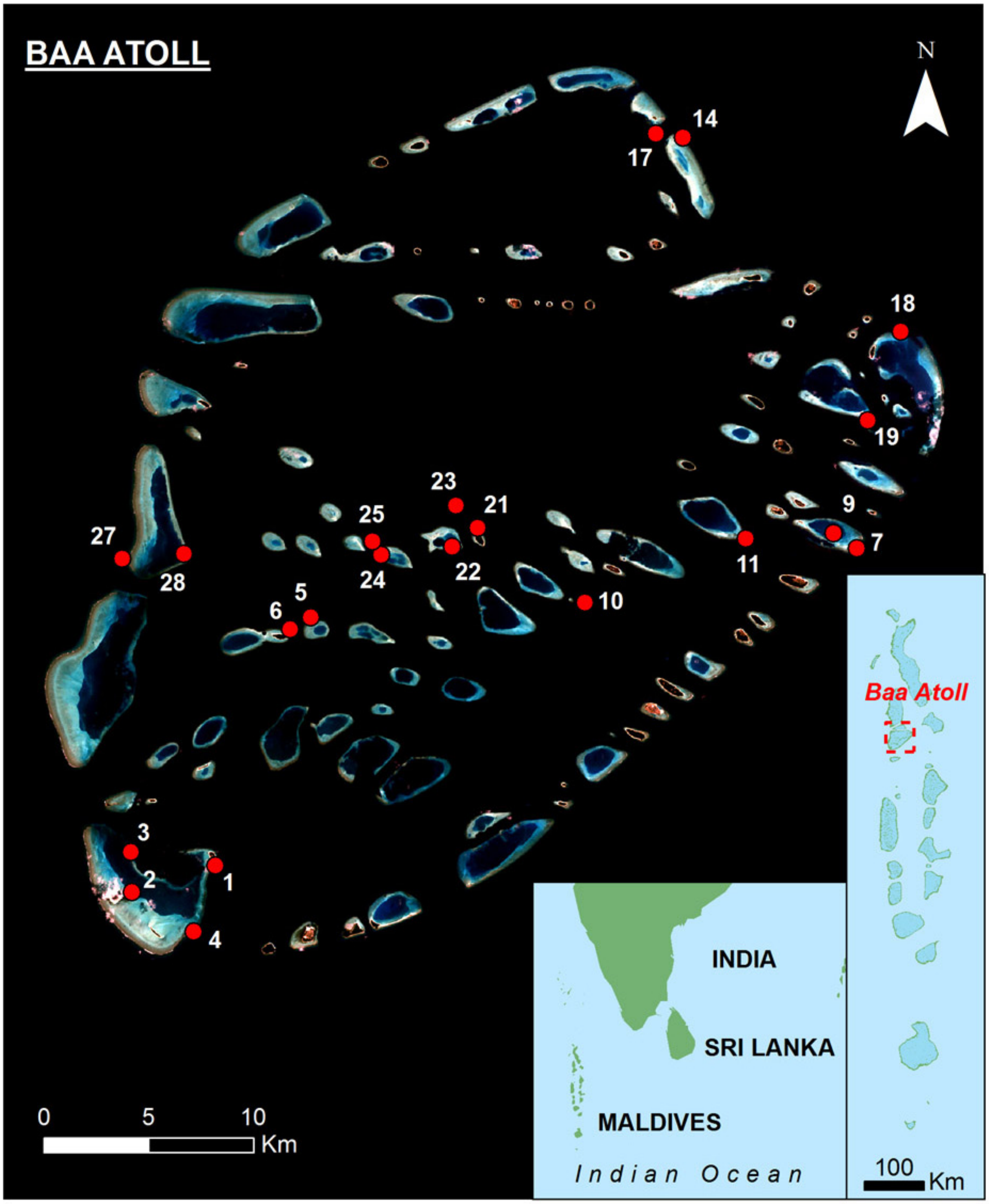


Figure 1. Location of Baa Atoll and macro-invertebrates sampling stations.

The converging richness values for different strata suggest that around 35 species per habitat is the richness limit that can be reached given the sampling method (Fig. 3 and Fig. 4). Obviously, additional species will appear by searching in cryptic spaces, by night, during longer dives, and for more sampling sites per strata.

The turn over of species per station was high, highlighting ecological rarity in Baa Atoll macro-invertebrates community. More than half of the species (n=95) were found in only one station, suggesting that macro-invertebrates beta-diversity as it was sampled here in Baa Atoll reefs is high (Fig. 4). The most frequently encountered species were the starfish *Linckia multifora* (found on 17 stations), the pin-cushion seastar *Culcita schmedeliana* (15 stations) and the holothurian *Pearsonothuria graeffei* (15 stations). Two specimen of *Acanthaster plancii* were found in station 25 only during the macro-invertebrate surveys, although others have been seen during the habitat survey in station 23.

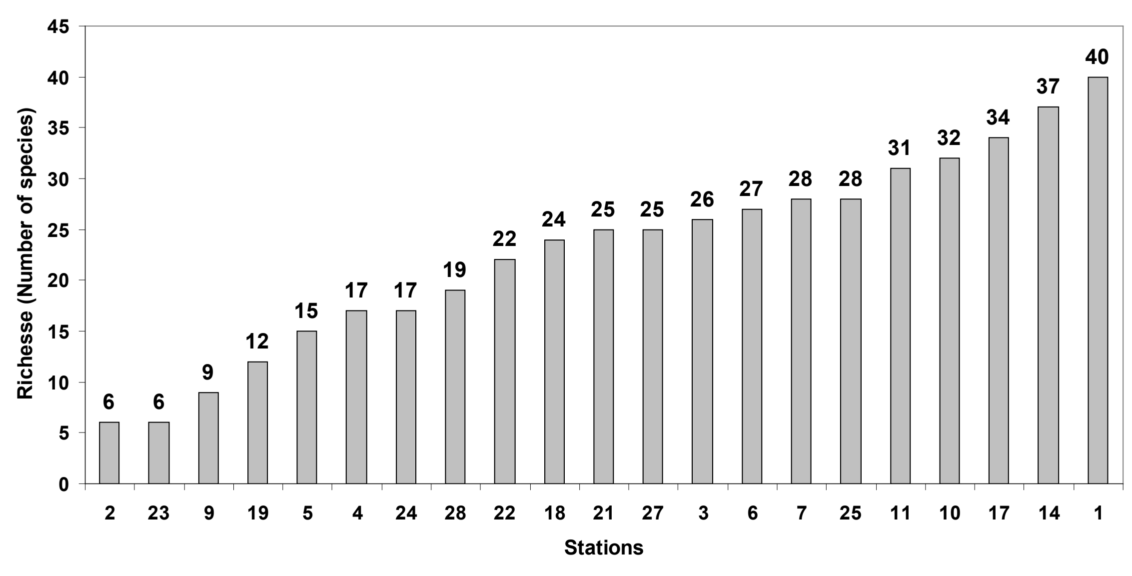


Figure 2. Variation of species richness per sampled station.

Similar high turnover of species was noted for macromollusc species in Tuamotu atolls in the Central Pacific Ocean (Pante et al., 2006), with 70% of 27 species encountered in only one or two habitats. A systematic comparison with the study by Adjeroud et al. (2000) and Pante et al. (2006) is not possible since they focused on lagoon habitats only and considered different type of habitats and geomorphological strata than the present study, and not all the phylum considered here. However, as seen in Figure 4, lagoon habitats sheltered an average of about 25 species in Baa Atoll. All lagoon habitats yielded a total of 94 species mollusks and echinoderms species. In average, lagoon stations provided 15.0 ± 3.9 species (mean ± stdev, n=13). In contrast, Adjeroud et al. (2000) listed a grand total of 36 species in 9 atolls, thus nearly 1/3 less than in Baa alone. They also reported a range of lagoon-scale richness between 2 and 22 for 9 atoll lagoons, with 10.4 ± 7.1 species (mean ± stdev, n=9).

Pearse (2009) reported for shallow water asteroids, echinoids and holothuroids in 6 Pacific Ocean sites that 56% of the 113 species were found in only one site. Thus, we found a similar ratio of single species in Baa Atoll than in a Pacific wide search suggesting that rarity could obey pattern across multiple spatial and biogeographical scales but this warrants larger tropical investigations on invertebrates community structure (Iken et al., 2010).

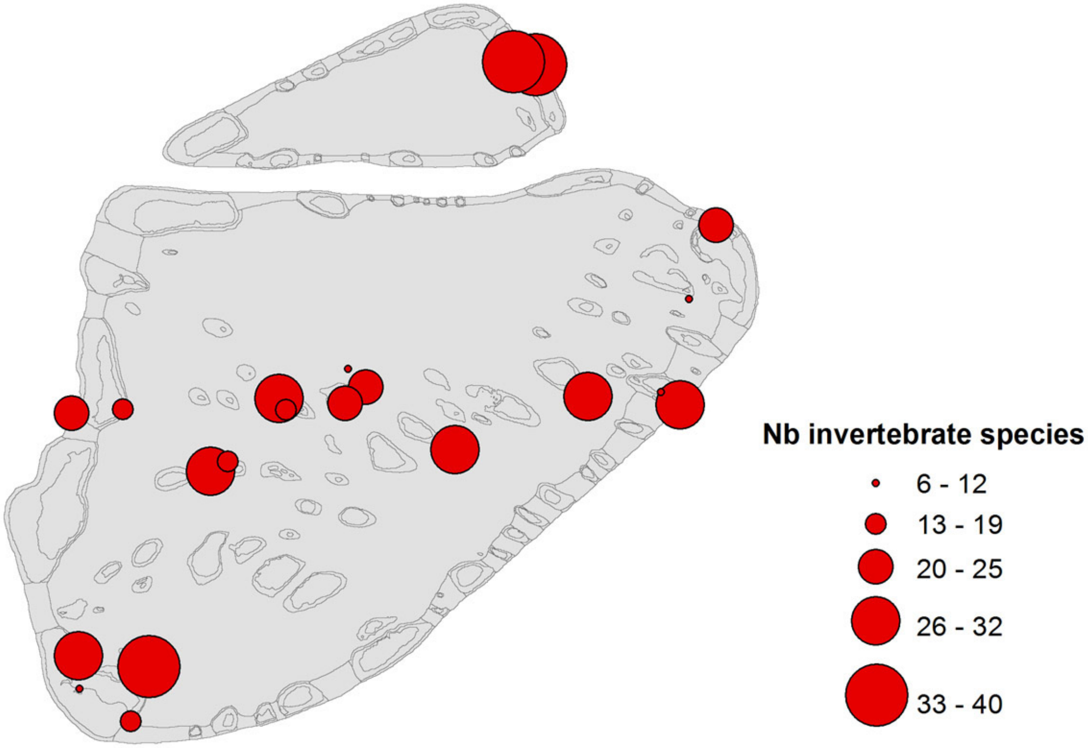


Figure 3. Mapped species richness for the 21 stations (Fig. 1).

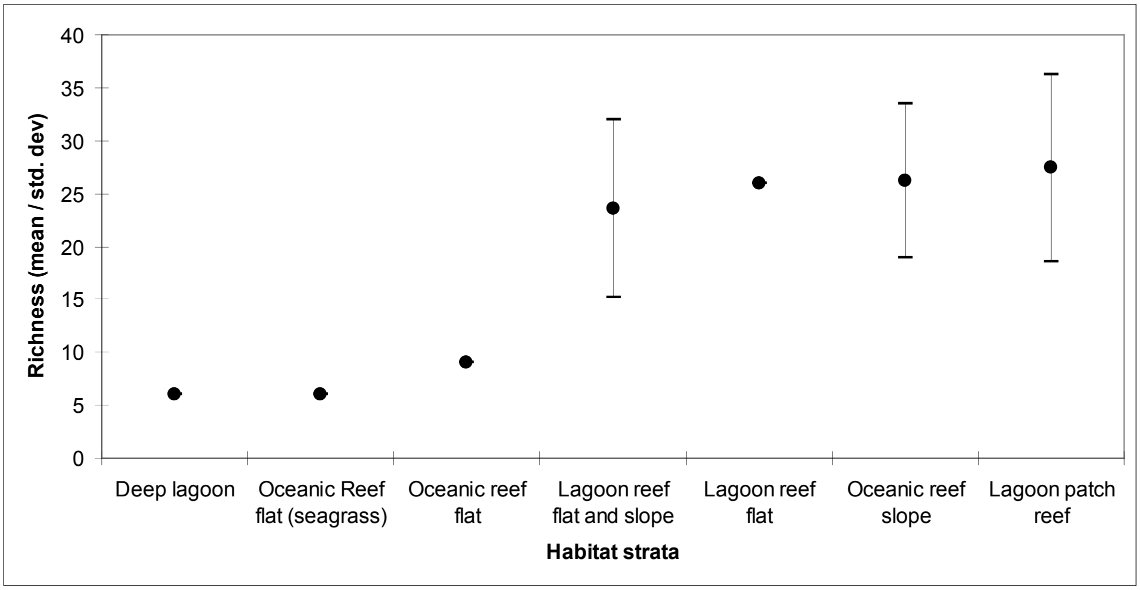


Figure 4. Variation of richness per habitat.

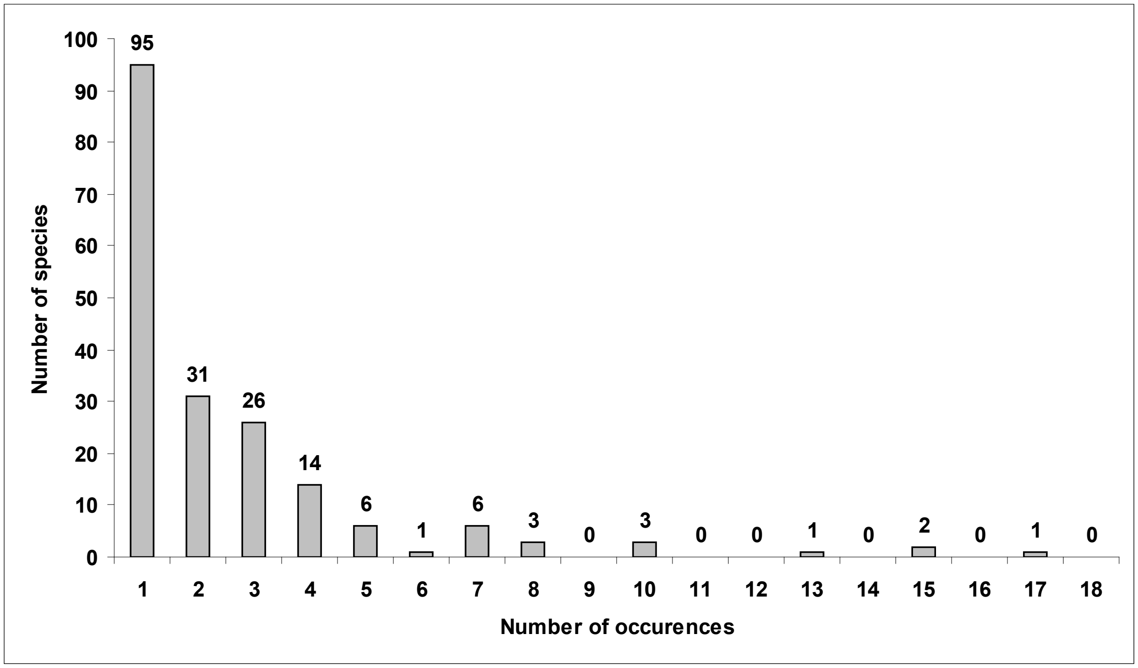


Figure 5. Histogram of species occurrences for the 21 sites.

Similar observations on high beta-diversity can be made at the genera level. 127 genera were identified and recorded, and 50 were found only once. Half of the genera were found only once or twice. The most frequently found genera were the echinoderms *Linckia, Culcita, Pearsonothuria and Choriaster* found in 18, 17, 15, and 13 stations respectively. Next was the mollusk genera *Tridacna* with 11 stations.

Few recent (in the past 20 years) publications have updated taxonomic check-lists for macro-invertebrates in the Maldives (e.g. for 47 species of brachyuran crabs in Laamu Atoll, see Kumar and Wesley, 2010) and none to our knowledge which would be Baa-specific. Commercial macro-invertebrate resources were the object of national-scale fishery reports, specifically for clams (Basker, 1991) and sea cucumbers (Joseph, 1992). Both authors reported that these fisheries were already unsustainable with quickly depleting resources. Clams (both *Tridacna maxima* and *T. squamosa*) were actually more present in Baa than what Table 1 suggests. Indeed, they were seen on virtually all stations of the survey completed for habitat mapping (Andréfouët et al., this issue). They may have been missed during the macro-invertebrate survey given the longer time spent at depth than in the shallows (between 0 and 5 meters) where they are more abundant. For sea cucumbers, Joseph (1992) listed 9 species commonly fished throughout Maldives, and refer to an 1988 expedition by a Maldives/China UNDP/ESCAP pilot study that listed 8 species identified from Baa, Haa Alifu and Haa Dhaalu Atolls, namely *Bohadschia marmorata, Actinopyga lecanora, A. mauritiana, Holothuria (Halodeima) atra, H. leucospilota, H. (Microthele) nobilis, Stichopus chloronotus,* and *Synapta maculata*. The last four of these 8 species were not found in the 2009 Baa survey which yielded a total of 12 species (Table 1).

In Diego Garcia, an atoll of the Chagos Archipelago in the south of Maldives, Clark and Taylor (1971) reported for the Echinodermata phyla, 9, 11, 1 and 14 species for respectively the Echinoidea, Ophiuroidea, Asteroida and Holothuroidea classes. In Baa, we report here respectively 7, 11, 10 and 12 species for the same classes, thus similar values, except for the Asteroida. Conversely, Taylor (1971) reported for Diego Garcia 179 species of mollusks alone, *vs* 63 species here (class Bivalvia n=14, Cephalopoda n=1 and Gastropoda n=48). Overall, the Mollusca phylum appears undersampled in Baa compared to other check-lists published for the region in the past (e.g. Kohn and Robertson (1968) for conidae).

CONCLUSION

The image of the benthic fauna made from the distribution of sponges, sea stars, urchins, holothurians, crinoids, ophiuroids, ascidians, bivalves, gastropods, anemones, zooanthids, anthipatharian, gorgonians, alcyonaceans, and flatworms provided a fresh view of the Baa Atoll benthic macro-invertebrate richness. This assessment is obviously dependent on the sampling strategy applied in May-June 2009, and for the sake of knowledge more detailed census with larger resources remain worth investigating for Baa, and for the Maldives in general. Nevertheless, the results presented here update the level of knowledge of Baa atoll and Maldives biodiversity.

The taxonomic inventory performed here brings a different biodiversity layer to guide conservation planning than what was usually done for coral reef ecosystems. Conservation planning is dependent on optimization algorithms, and these algorithms often use richness and rarity, and complementarity between sites to converge towards a solution able to fill the conservation targets. Given the beta-diversity patterns observed here, further work will investigate the sensitivity of conservation planning and siting algorithms to the macro-invertebrate layer.

ACKNOWLEDGEMENTS

This work is a contribution to the program “Biodiversity of Indian Ocean Islands” of the French Fondation pour la Recherche sur la Biodiversité. Gratitude is expressed to Shiham Adam, Hussain Zahir and Thomas Le Berre for scientific collaboration during the field survey, and to the Atoll Ecosystem Conservation Project for funding.

REFERENCES

Adjeroud, M., S. Andréfouët, C. Payri, and J. Orempuller.
2000. Physical factors of differentiation in macrobenthic communities between atoll lagoons in the Central Tuamotu Archipelago (French Polynesia). *Marine Ecology Progress Series* 196:39-48.

Basker, J.
1991. Giant clams in the Maldives. A stock assessment and study of their potential for culture. Bay of Bengal Program. Food and Agriculture Organisation of the United Nations, Report BOPB/WP/72, Madras, India. 24 p.

Bouchet, P., Le Guyader, H. and Pascal, O.
2011. The natural history of Santo. Vol. 69. Muséum National d'Histoire Naturelle, Paris ; Institut de Recherche pour le Développement, Paris, Marseille ; Pro-Natura International, Paris. 572 p.

Clark, A.M., and F. W. E. Rowe
1971. Monograph of shallow water Indo-Pacific echinoderms. British Museum (Natural History), London, Pub. 690. 306 p. (with Plates and references)

Clark, A. M., and J. D. Taylor
1971. Echinoderms from Diego Garcia. *Atoll Research Bulletin* 149:89-92

Taylor, J.D.
1971. Marine Mollusca from Diego Garcia. *Atoll Research Bulletin* 149:105-126

Coleman, N.
2000. Marine life of the Maldives. Atoll Editions. 352 p.

Colin, P., and C. Arneson
1995. Tropical Pacific Invertebrates: a field guide to the marine invertebrates occuring on tropical Pacific coral reefs, seagrass beds, and mangroves. Coral Reef Press, Beverly Hills, USA. 296 p.

Glynn, P. W., and I. C. Enochs
2011. Invertebrates and their roles in coral reef ecosystems. Pages 273-325 in Z. Dubinsky and N. Stambler (Eds) *Coral reefs: an ecosystem in transition.* Springer, Berlin.

Guille, A., P. Laboute, and J. Menou
1986. Handbok of the sea-stars, sea-urchins, and related echinoderms of New-Caledonia lagoon. ORSTOM, Paris. 239 p.

Grasshoff, M., and G. Bargibant
2001. Coral reef gorgonians of New Caledonia. IRD, Paris. 336 p.

Hervé, J.F
2010. Guides des nudibranches de Nouvelle-Calédonie et autres Opisthobranches. Ed. Catherine Ledru – IRD, Nouméa, Nouvelle-Calédonie, 401 p.

Iken, K. and 17 authors
2010. Large-scale spatial distribution patterns of echinoderms in nearshore rocky habitats. Plos ONE 5 :e13845

Joseph, L.
1992. Review of the bêche de mer (sea cucumber) fishery in the Maldives. Bay of Bengal Program. Food and Agriculture Organisation of the United Nations, report BOPP/WP/79 Madras, India. 34 p.

Kohn, A. J., and R. Robertson.
1968. The Conidae (Gastropoda) of the Maldive and Chagos Archipelagoes. *J. Mar. Biol. Ass. India* 8: 273-277

Kumar, A. A. J., and S. G. Wesley.
2010. Spatio-temporal distribution of assemblages of brachyuran crabs at Laamu Atoll, Maldives. *Atoll Research Bulletin* 588:1-15.

Laboute, P., and B. Richer de Forges
2004. Lagons et récifs de Nouvelle-Calédonie. Editions Ledru, IRD, Nouméa. 520 p.

Le Berre T., Emanuelli E., Roussel E., Guignard C., Sivad A., Saleem M., Zahir H.
2009. Rapid marine ecological baseline assessment of islands of Baa atoll. *Technical report SEAMARC, Atoll Ecosystem Conservation Project,* 156 pp.

Lévi, C., P. Laboute, G. Bargibant, and J. Menou
1998. Sponges of the New Caledonia lagoon. ORSTOM, Paris. 215 p.

McKenna, S. A., G. R. Allen, and S. Suryadi.
2002. A marine rapid assessment of the Raja Ampat Islands, Papua Province, Indonesia. RAP Bulletin 22. Conservation International, Washington. 195 p.

McKenna, S. A., N. Baillon, and J. Spaggiari.
2009. Rapid marine biodiversity assessment of the coral reefs of the northwest lagoon, between Koumac and Yandé, Province Nord, New Caledonia. RAP Bulletin of Biological Assessment 53. Conservation International, Washington. 184 p.

Monniot, C., F. Monniot, and P. Laboute
1991. Coral reef ascidians of New Caledonia. ORSTOM, Paris. 248 p.

Pante, E., M. Adjeroud, P. Dustan, L. Penin, and M. Schrimm.
2006. Spatial patterns of benthic invertebrate assemblages within atoll lagoons: importance of habitat heterogeneity and considerations for marine protected area design in French Polynesia. *Aquatic Living Resource* 19:207-217.

Paulay, G. H.
2003. Marine biodiversity of Guam and the Mariannas. *Micronesica*. 35-36:456-513

Payri, C., and B. Richer de Forges
2007. Compendium of marine species of New Caledonia. IRD, Centre de Nouméa, Nouméa. 435p. + 19 plates

Pearse, J.
2009. Shallow water asteroids, echinoids and holothuroids at 6 sites across the tropical west Pacific; 1988-1989. *Galaxea* 11:187-195

Poupin, J. and M. Juncker
2010. A guide to the decapode crustacean of the South Pacific/ Guide des crustacés décapodes du Pacifique Sud. CRISP/SPC, Nouméa, Nouvelle-Calédonie, 320 p.

Ramohia, P.
2006. Fisheries resources: commercially important macroinvertebrates. In: Green, A., P. Lokani, W. Atu, P. Ramohia, P. Thomas and J. Almany (eds). 2006. Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004. TNC Pacific Island Countries Report No 1/06. pp.329-400

Table 1. Check list of macro-invertebrates species for the 21 sampled stations (1=presence).

					Stations																				
Phylum	**Class**	**Order**	***Genera***	***Species***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**11**	**14**	**17**	**18**	**19**	**21**	**22**	**23**	**24**	**25**	**27**	**28**
Annelida	Polychaeta	Sabellida	*Sabellastarte*	*indica*																1					
Chordata	Ascidiacea	Aplousobranchia	*Didemnum*	*molle*	1		1								1	1	1	1					1	1	1
Chordata	Ascidiacea	Aplousobranchia	*Diplosoma*	*versicolor*															1						
Chordata	Ascidiacea	Aplousobranchia	*Eudistoma*	*sp.*																				1	
Chordata	Ascidiacea	Aplousobranchia	*Polysynchraton*	*sp.*												1									
Chordata	Ascidiacea	Phlebobranchia	*Ascidia*	*glabra*			1								1	1	1								
Chordata	Ascidiacea	Stolidobranchia	*Botrylloides*	*sp.*										1											
Chordata	Ascidiacea	Stolidobranchia	*Pyura*	*gangelion*			1								1										
Cnidaria	Anthozoa	Actiniaria	*Actinodendron*	*arborum*	1																				
Cnidaria	Anthozoa	Actiniaria	*Heteractis*	*magnifica*						1			1									1	1		
Cnidaria	Anthozoa	Actiniaria	*Stichodactyla*	*cf mertensii*					1				1												
Cnidaria	Anthozoa	Actiniaria	*Dofleina*	*sp.*									1					1							
Cnidaria	Anthozoa	Actiniaria	*Heteractis*	*aurora*									1												
Cnidaria	Anthozoa	Actiniaria	*Actinodendron*	*cf. plumosum*																1					
Cnidaria	Anthozoa	Actiniaria	*Discosoma*	*sp.*																1		1			
Cnidaria	Anthozoa	Actiniaria	*Entacmea*	*quadricolor*																		1	1		
Cnidaria	Anthozoa	Alcyonacea	*Dendronephthya*	*sp.1*						1	1			1		1									
Cnidaria	Anthozoa	Alcyonacea	*Chironephthya*	*sp.1*										1		1									
Cnidaria	Anthozoa	Alcyonacea	*Chironephthya*	*sp.2*												1									
Cnidaria	Anthozoa	Alcyonacea	*Dendronephthya*	*sp.2*									1												
Cnidaria	Anthozoa	Alcyonacea	*Dendronephthya*	*sp.3*										1											
Cnidaria	Anthozoa	Alcyonacea	*Subergorgia*	*sp.*						1															
Cnidaria	Anthozoa	Alcyonacea	*Acanthogorgia*	*sp.1*						1															
Cnidaria	Anthozoa	Alcyonacea	*Acabaria*	*sp.1*					1							1									
Cnidaria	Anthozoa	Alcyonacea	*Acabaria*	*sp.2*								1	1	1											
Cnidaria	Anthozoa	Alcyonacea	*Acabaria*	*sp.3*										1		1									
Cnidaria	Anthozoa	Alcyonacea	*Annella*	*mollis*											1										
Cnidaria	Anthozoa	Alcyonacea	*Acanthogorgia*	*sp.2*											1										
Cnidaria	Anthozoa	Alcyonacea	*Acanthogorgia*	*sp.3*											1										
Cnidaria	Anthozoa	Antipatharia	*Stichopathes*	*sp.*	1					1	1		1	1	1	1									
Cnidaria	Anthozoa	Antipatharia	*Cirrhipathes*	*sp. cf. anguineus*	1								1		1										
Cnidaria	Anthozoa	Antipatharia	*Antipathes*	*sp.1*						1	1			1											
Cnidaria	Anthozoa	Antipatharia	*Antipathes*	*sp.3*				1		1						1	1								
Cnidaria	Anthozoa	Antipatharia	*Antipathes*	*sp.4*												1									
Cnidaria	Anthozoa	Antipatharia	*Antipathes*	*sp.5*									1		1	1									
Cnidaria	Anthozoa	Antipatharia	*Antipathes*	*sp.6*												1									
Cnidaria	Anthozoa	Zoanthidea	*Palythoa*	*caesia*	1		1	1	1				1		1									1	
Cnidaria	Anthozoa	Zoanthidea	*Zoanthus*	*mantoni*																		1			
Cnidaria	Anthozoa	Zoanthidea	*Protopalythoa*	*sp.*																			1		1
Cnidaria	Anthozoa	Zoanthidea	*Zoanthus*	*sp.*						1															
Cnidaria	Anthozoa	Zoanthidea	*Parazoanthus*	*sp.*												1							1		
Cnidaria	Anthozoa	Zoanthidea	*Palythoa*	*caesia cf.tuberculosa*											1										
Echinodermata	Asteroidea	Spinulosida	*Acanthaster*	*planci*																			1		
Echinodermata	Asteroidea	Valvatida	*Choriaster*	*granulatus*	1	1	1	1		1			1	1	1	1			1		1		1	1	
Echinodermata	Asteroidea	Valvatida	*Culcita*	*schmedeliana*	1	1	1	1		1		1	1		1	1	1		1			1	1	1	1
Echinodermata	Asteroidea	Valvatida	*Linckia*	*guildingi*	1					1	1													1	1
Echinodermata	Asteroidea	Valvatida	*Culcita*	*cf. novaeguineae*					1												1				
Echinodermata	Asteroidea	Valvatida	*Linckia*	*multifora*	1		1	1		1		1	1		1	1	1	1	1		1	1	1	1	1
Echinodermata	Asteroidea	Valvatida	*Fromia*	*indica*			1			1									1						
Echinodermata	Asteroidea	Valvatida	*Gomophia*	*sp.*																1					
Echinodermata	Asteroidea	Valvatida	*Fromia*	*milleporella*						1					1										
Echinodermata	Asteroidea	Valvatida	*Fromia*	*nodosa*					1				1						1	1	1		1		
Echinodermata	Crinoidea	Comatulida	*Comanthus*	*parvicirrus*			1								1	1	1								
Echinodermata	Crinoidea	Comatulida	*Comanthina*	*schlegeli*									1	1			1								

Table 1 (Con'td)

					Stations																				
Phylum	**Class**	**Order**	***Genera***	***Species***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**11**	**14**	**17**	**18**	**19**	**21**	**22**	**23**	**24**	**25**	**27**	**28**
Echinodermata	Crinoidea	Comatulida	*Capillaster*	*sp.*				1				1	1							1			1		
Echinodermata	Crinoidea	Comatulida	*Comanthus*	*sp.2*										1			1		1						
Echinodermata	Crinoidea	Comatulida	*Comaster*	*sp.*																1					
Echinodermata	Crinoidea	Comatulida	*Comanthus*	*cf. parvicirrus*											1	1							1		
Echinodermata	Crinoidea	Comatulida	*Stephanometra*	*sp.*																1					
Echinodermata	Echinoidea	Diadematoida	*Echinothrix*	*calamaris*							1														
Echinodermata	Echinoidea	Diadematoida	*Diadema*	*savignyi*	1																				
Echinodermata	Echinoidea	Echinoida	*Echinostrephus*	*molaris*	1			1							1	1	1							1	1
Echinodermata	Echinoidea	Echinoida	*Heterocentrotus*	*mammillatus*	1		1																		
Echinodermata	Echinoidea	Echinoida	*Echinometra*	*mathaei*	1		1																		
Echinodermata	Echinoidea	Spatangoida	*Metalia*	*sp1-cf sternalis*	1							1			1					1	1				
Echinodermata	Echinoidea	Spatangoida	*Schizaster*	*sp.*														1							
Echinodermata	Holothuroidea	Apodida	*Synaptula*	*sp.*																		1			
Echinodermata	Holothuroidea	Aspidochirotida	*Pearsonothuria*	*graeffei*	1		1	1	1	1	1		1	1	1	1	1		1			1		1	1
Echinodermata	Holothuroidea	Aspidochirotida	*Holothuria*	*fuscogilva*						1															
Echinodermata	Holothuroidea	Aspidochirotida	*Actinopyga*	*lecanora*							1														
Echinodermata	Holothuroidea	Aspidochirotida	*Bohadschia*	*argus*																		1	1		
Echinodermata	Holothuroidea	Aspidochirotida	*Bohadschia*	*marmorata sp1*		1							1												
Echinodermata	Holothuroidea	Aspidochirotida	*Bohadschia*	*marmorata sp2*										1											
Echinodermata	Holothuroidea	Aspidochirotida	*Actinopyga*	*mauritiana*			1																		
Echinodermata	Holothuroidea	Aspidochirotida	*Thelenota*	*ananas*																				1	
Echinodermata	Holothuroidea	Aspidochirotida	*Thelenota*	*anax*									1	1					1					1	
Echinodermata	Holothuroidea	Aspidochirotida	*Holothuria (Halodeima)*	*edulis*																			1		
Echinodermata	Holothuroidea	Aspidochirotida	*Holothuria (Halodeima)*	*atra*															1	1		1			
Echinodermata	Ophiuroidea	Ophiurida	*Ophiothrix (Acanthophiothrix)*	*sp1*					1								1							1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophiothela*	*danae*					1																
Echinodermata	Ophiuroidea	Ophiurida	*Ophiocoma*	*erinaceus*	1		1	1			1		1	1	1	1			1					1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophiolepis*	*cf. cincta*																				1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophiarthrum*	*elegans*											1	1								1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophiothrix*	*sp.2*														1							
Echinodermata	Ophiuroidea	Ophiurida	*Ophiothrix*	*sp.3*																			1		
Echinodermata	Ophiuroidea	Ophiurida	*Ophionereis*	*sp.1*											1										
Echinodermata	Ophiuroidea	Ophiurida	*Ophiarachnella*	*cf. gorgonia*																				1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophiothrix (Acanthophiothrix)*	*purpurea*						1														1	
Echinodermata	Ophiuroidea	Ophiurida	*Ophionereis*	*sp.2*																1					
Mollusca	Bivalvia	Arcoida	*Arca*	*ventricosa*					1			1												1	
Mollusca	Bivalvia	Ostreoida	*Hyotissa*	*hyotis*	1		1		1	1							1		1				1	1	
Mollusca	Bivalvia	Ostreoida	*Lopha*	*cristagalli*									1	1										1	
Mollusca	Bivalvia	Pectinoida	*Spondylus*	*varians*				1						1	1	1								1	
Mollusca	Bivalvia	Pectinoida	*Spondylus*	*sp.*																1					
Mollusca	Bivalvia	Pterioidea	*Pinctada*	*margaritifera*											1	1						1			
Mollusca	Bivalvia	Pterioidea	*Pinna*	*sp.*																		1			
Mollusca	Bivalvia	Pterioidea	*Pteria*	*penguin*									1	1										1	
Mollusca	Bivalvia	Veneroida	*Cardiidae*	*indéterminé*	1																				1
Mollusca	Bivalvia	Veneroida	*Cardium*	*sp.*														1							
Mollusca	Bivalvia	Veneroida	*Globivenus*	*toreuma*												1									
Mollusca	Bivalvia	Veneroida	*Tapes*	*literatus*																			1		
Mollusca	Bivalvia	Veneroida	*Tridacna*	*maxima*	1	1	1			1	1		1				1	1	1	1					
Mollusca	Bivalvia	Veneroida	*Tridacna*	*squamosa*						1										1		1			
Mollusca	Cephalopoda	Octopoda	*Octopus*	*cyanea*	1																				
Mollusca	Gastropoda	Caenogastropoda	*Cerithium*	*nodulosum*											1					1					
Mollusca	Gastropoda	Caenogastropoda	*Rhinoclavis*	*vertagus cf.*														1							
Mollusca	Gastropoda	Caenogastropoda	*Rhinoclavis*	*aspera*												1									1
Mollusca	Gastropoda	Littorinimorpha	*Cypraea*	*tigris*	1		1																		

Table 1 (Con'td)

Phylum	Class	Order	*Genera*	*Species*	Stations 1	2	3	4	5	6	7	9	10	11	14	17	18	19	21	22	23	24	25	27	28
Mollusca	Gastropoda	Littorinimorpha	*Cypraea*	*caputserpentis*							1														
Mollusca	Gastropoda	Littorinimorpha	*Cypraea*	*tigris*	1																				
Mollusca	Gastropoda	Littorinimorpha	*Cypraea*	*linx*																					1
Mollusca	Gastropoda	Littorinimorpha	*Dendropoma*	*maximum*			1		1		1			1											
Mollusca	Gastropoda	Littorinimorpha	*Lambis*	*lambis*			1																		
Mollusca	Gastropoda	Littorinimorpha	*Lambis*	*chiragra arthritica*			1						1		1										1
Mollusca	Gastropoda	Littorinimorpha	*Lambis*	*truncata truncata*						1	1												1		
Mollusca	Gastropoda	Littorinimorpha	*Monoplex*	*aquatilis*																					1
Mollusca	Gastropoda	Littorinimorpha	*Septa*	*rubecula*							1														
Mollusca	Gastropoda	Littorinimorpha	*Serpulorbis*	*grandis*	1		1		1		1		1				1			1		1			
Mollusca	Gastropoda	Littorinimorpha	*Strombus (canarium)*	*sp.cf. dentatum*													1								
Mollusca	Gastropoda	Neogastropoda	*Acus*	*crenulatus*	1																				
Mollusca	Gastropoda	Neogastropoda	*Benimakia*	*nodata*																		1			
Mollusca	Gastropoda	Neogastropoda	*Chicoreus*	*microphyllus*	1												1								
Mollusca	Gastropoda	Neogastropoda	*Chicoreus*	*sp2*					1					1			1								
Mollusca	Gastropoda	Neogastropoda	*Chicoreus*	*palmarosae*	1						1														
Mollusca	Gastropoda	Neogastropoda	*Chicoreus*	*ramosus*																				1	
Mollusca	Gastropoda	Neogastropoda	*Conus*	*eburneus*				1																	
Mollusca	Gastropoda	Neogastropoda	*Conus*	*lithoglyphus*													1								
Mollusca	Gastropoda	Neogastropoda	*Conus*	*virgo*	1																				
Mollusca	Gastropoda	Neogastropoda	*Conus*	*miliaris*			1																		
Mollusca	Gastropoda	Neogastropoda	*Conus*	*miles cf.*															1						
Mollusca	Gastropoda	Neogastropoda	*Conus*	*arenatus cf.*																					1
Mollusca	Gastropoda	Neogastropoda	*Conus*	*emaciatus cf.*										1											1
Mollusca	Gastropoda	Neogastropoda	*Conus*	*bandanus*														1							
Mollusca	Gastropoda	Neogastropoda	*Conus*	*distans*							1														
Mollusca	Gastropoda	Neogastropoda	*Drupa*	*sp.*																					1
Mollusca	Gastropoda	Neogastropoda	*Drupa*	*ricina arachnoides*	1						1														
Mollusca	Gastropoda	Neogastropoda	*Harpa*	*amouretta*															1						
Mollusca	Gastropoda	Neogastropoda	*Latirolagena*	*smaragdula*																			1		
Mollusca	Gastropoda	Neogastropoda	*Latirus*	*sp1*							1														
Mollusca	Gastropoda	Neogastropoda	*Mitra*	*mitra*		1																			
Mollusca	Gastropoda	Neogastropoda	*Mitra*	*cf. contracta*											1										
Mollusca	Gastropoda	Neogastropoda	*Myurella*	*affinis*									1												
Mollusca	Gastropoda	Neogastropoda	*Pleuroploca*	*glabra cf.*												1									
Mollusca	Gastropoda	Neogastropoda	*Thais*	*mancinella*																		1			1
Mollusca	Gastropoda	Neogastropoda	*Turrilatirus*	*turritus*												1									
Mollusca	Gastropoda	Neogastropoda	*Vasum*	*ceramicum cf.*							1														
Mollusca	Gastropoda	Nudibranchia	*Nembrotha*	*megalocera*																			1		
Mollusca	Gastropoda	Nudibranchia	*Phyllidia*	*varicosa*													1	1					1		1
Mollusca	Gastropoda	Nudibranchia	*Phyllidiella*	*rudmani*	1		1																		
Mollusca	Gastropoda	Nudibranchia	*Phyllidiella*	*rosans*										1											
Mollusca	Gastropoda	Trochoidea (super family)	*Tectus*	*maculatus*						1				1											1
Mollusca	Gastropoda	Trochoidea (super family)	*Tectus*	*pyramis*													1								
Platyhelminthes	Turbellaria	Polycladida	*Maiazoon*	*orsaki*													1								
Porifera	Calcarea	Clathrinida	*Clathrina*	*sp.*																			1		
Porifera	Calcarea	Clathrinida	*Leucetta*	*chagosensis*			1							1	1									1	
Porifera	Calcarea	Clathrinida	*Pericarax*	*sp.*																1					
Porifera	Demospongiae	Astrophorida	*Stelletta*	*clavosa*															1						
Porifera	Demospongiae	Dendroceratida	*Dendrylla*	*sp.*															1						
Porifera	Demospongiae	Dictyoceratida	*Carteriospongia*	*foliascens*		1																			
Porifera	Demospongiae	Dictyoceratida	*Dactylospongia*	*metachromia*											1	1			1						

Table 1 (Con'td)

					Stations																				
Phylum	**Class**	**Order**	***Genera***	***Species***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**9**	**10**	**11**	**14**	**17**	**18**	**19**	**21**	**22**	**23**	**24**	**25**	**27**	**28**
Porifera	Demospongiae	Dictyoceratida	*Hyrtios*	*erectus*					1					1											
Porifera	Demospongiae	Dictyoceratida	*Lamellodysidea*	*chlorea*	1																			1	1
Porifera	Demospongiae	Halicondrida	*Auletta*	*sp.*																1					
Porifera	Demospongiae	Halicondrida	*Axinella*	*labyrinthica*							1														
Porifera	Demospongiae	Halicondrida	*Dragmacidon*	*australe*				1		1	1	1	1	1	1	1									
Porifera	Demospongiae	Halicondrida	*Liosina*	*paradoxa*																			1		
Porifera	Demospongiae	Halicondrida	*Phakellia*	*carteri*	1			1				1	1	1	1								1		
Porifera	Demospongiae	Halicondrida	*Phakellia*	*cf. cavernosa*				1		1	1				1										
Porifera	Demospongiae	Halicondrida	*Stylissa*	*flabelliformis*				1			1		1						1				1		
Porifera	Demospongiae	Haplosclerida	*Amphimedon*	*sp.*	1									1			1								
Porifera	Demospongiae	Haplosclerida	*Amphimedon*	*cf.viridis*	1		1				1					1				1		1	1		
Porifera	Demospongiae	Haplosclerida	*Haliclona*	*nematifera*									1												
Porifera	Demospongiae	Haplosclerida	*Haliclona*	*ostros*	1														1						
Porifera	Demospongiae	Haplosclerida	*Microxina*	*sp.*							1				1		1				1				
Porifera	Demospongiae	Haplosclerida	*Niphates*	*sp.*																			1		
Porifera	Demospongiae	Homoscleromorpha	*Plakortis*	*sp.*	1													1	1						
Porifera	Demospongiae	Poecilosclerida	*Acarnus*	*sp.*	1				1		1			1											
Porifera	Demospongiae	Poecilosclerida	*Clathria (Microciona)*	*plinthina*	1					1						1		1							
Porifera	Demospongiae	Poecilosclerida	*Monanchora*	*unguiculata*						1						1									
Porifera	Demospongiae	Spirophorida	*Craniella*	*abracadabra*																1					
Porifera	Demospongiae	Spirophorida	*Paratetilla*	*bacca*	1		1			1		1	1						1				1		
Porifera	Demospongiae	Verongida	*Pseudoceratina*	*verrucosa*															1						

Plate 1: Specimen of the Echinodermata phylum photographed in situ
(photos: Jean-Louis Menou).

Linckia multifora

Choriaster granulatus.

Comanthina schlegeli

Fromia indica

Bohadschia marmorata

Holothuria fuscogilva

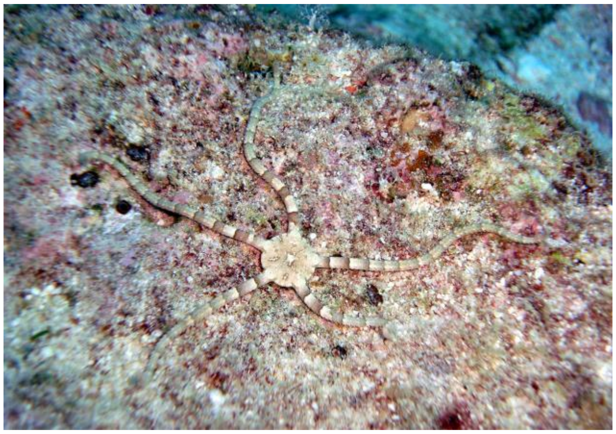
Plate 2: Specimen of the Echinodermata phylum photographed in situ
(photos: Jean-Louis Menou).

Culcita cf novaeguineae

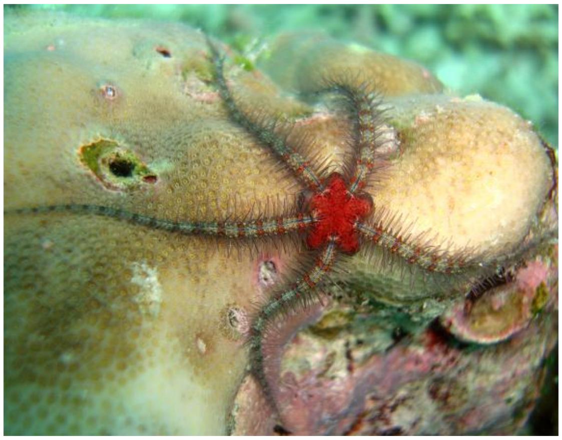
Culcita schmedeliana.

Echinostrephus molaris

Echinometra mathaei



Ophiarachnella cf. gorgonia



Ophiothrix sp.

Plate 3: Specimen of the Cnidaria phylum photographed in situ
(photos: Jean-Louis Menou).

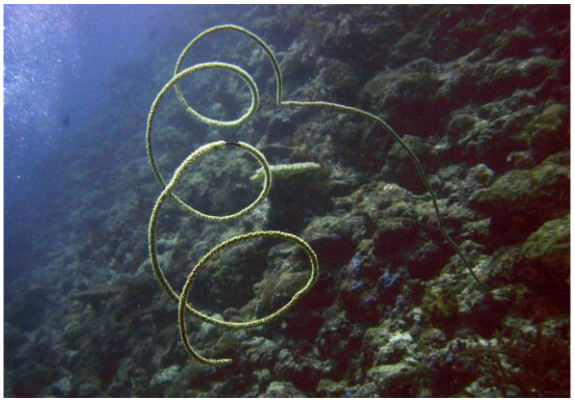
Heteractis aurora

Entacmea quadricolor

Chironephthya sp.

Dendronephthya sp.

Acanthogorgia sp.



Cirrhipathes cf. anguineus.

Plate 4: Specimen of the Porifera phylum photographed in situ
(photos: Jean-Louis Menou).

Phakellia carterii

Paratetilla bacca

Carteriospongia foliascens.

Clathria (Microciona) plinthina

Haliclona nematifera

Haliclona ostros

CHECKLIST OF THE CORAL REEF FISHES OF BAA ATOLL, MALDIVES

BY

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INTRODUCTION

The Maldives are an archipelago of nearly 1,200 coral islets forming a double chain of 26 atolls, which is situated in the Laccadive Sea, central Indian Ocean, southwest of India. Being a country with more territorial sea than land, the economy is essentially dependent on marine resources including fisheries, with fish providing more than 96% of animal proteins in the Maldives (Kent, 1997). Studies related to marine fish have been conducted primarily to address the concerns generated by the increase in economic development as the country has undergone rapid expansion and diversification since the late 1970.

Fisheries yields in the Maldives are largely composed of top-level predators such as tuna (MRS, 1996; Anderson et al., 1998; Adam and Kirkwood, 2001; Adam, 2006). However smaller species including baitfish such as silver sprat (Dussumieriidae), anchovies (Engraulidae) and fusiliers (Caesionidae), or reef fish such as sweepers (Pempheridae), cardinalfish (Apogonidae), damselfish (Pomacentridae) and triggerfish (Balistidae) are also targeted (Anderson and Hafiz, 1984; Adam and Jauharee, 2009). Shark fishing is one of the major secondary fishing activities in the Maldives (Anderson and Ahmed, 1993), which was developed as a response to a request from Asian markets (Martin and Hakeem, 2006), similar to live grouper fishery (Sattar and Adam, 2005). The marine aquarium trade is also experiencing rapid increase and more than 120 reef fish species are being exported, including species that are rare and vulnerable to overexploitation (Adam, 1995; Saleem and Adam, 2004). Due to the rise of tourism in the Maldives, the food demand for luxury fish such as groupers has dramatically increased (Adam, 2006; Newton et al., 2007). As a result, a decline in grouper populations is now observed. There is currently no enforced restriction on either baitfish or live grouper fishery (McClanahan, 2011). However, shark fishing is forbidden since 2008 (Anderson and Hafiz, 1984; Anderson and Ahmed, 1993).

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Despite an economy that is essentially depending on marine resources including fisheries, the reef fish stocks in the Maldives are among the least exploited in the Indian Ocean (Newton et al., 2007), as the artisanal fisheries have traditionally focused on pelagic species. The cultural preference to eat tuna is largely responsible for this condition (Risk and Sluka, 2000). Thus, Maldives reef fish communities are considered relatively undisturbed by fishing activities (Sluka and Miller, 2001; McClanaham, in press). A checklist of epipelagic and shore fishes of the Maldives Islands was compiled by Randall and Anderson (1993) who reported 899 species.

The project "Biodiversity, resources and conservation of the coral reefs of the Republic of Maldives" aims at studying the biodiversity of Maldives coral reefs. This checklist includes the shore fish species recorded from the upper 20 m at Baa Atoll.

SITES AND METHODS

The Baa Atoll is located in the northern third of the Maldives archipelago (5° 23' N - 4° 49'N) on the western side of the double chain of atolls making up the central Maldives (Fig. 1). The atoll, approximately 40 km long and wide, has a discontinuous rim characterised by numerous deep passages, which allow oceanic currents and waves to penetrate the lagoon. The study sites were chosen according to the representation of habitats within and outside the MPAs (Andrefouët et al., this issue). The twenty-one sampled stations for fish survey included shallow and deep strata including reef flat and reef slope (lagoon and outer reef), reef ridge (lagoon), pass slope (outer reef) and seagrass flat (Fig. 1).

The fish diversity (total number of species) was estimated using underwater visual census methods. At each station, species list was built from the combination of a 40 minutes random path and a 50 x 10 m belt transect. For some stations, small cryptic species were collected using an anaesthetic (eugenol) over 1m^2 of reef. Anderson's book (2005) has been used occasionally for fish identification. All surveys were conducted in June 2009.

In order to minimize the effect of the sampling effort and to enable a comparison between the diversities of different areas, some authors recommend the use of a theoretic species richness (SRth) (Werner & Allen, 1998; Allen & Werner, 2002). The calculation of SRth is based on the number of species (or CFDI = Coral Fish Diversity Index) of the six most common families easily observed underwater, i.e the Chaetodontidae, Pomacanthidae, Pomacentridae, Labridae, Acanthuridae and Scaridae. SRth is a function of the island size and for islands < 2,000 km^2 (e.g. the Maldives), SRth is calculated as follows (Allen & Werner, 2002):

$$\mathrm{SRth} = 3.39\ \mathrm{CFDI} - 20.595$$

We used this approach to compare reef fish diversity of Baa and the Maldives with that reported by other studies in other islands of Indian Ocean regions.

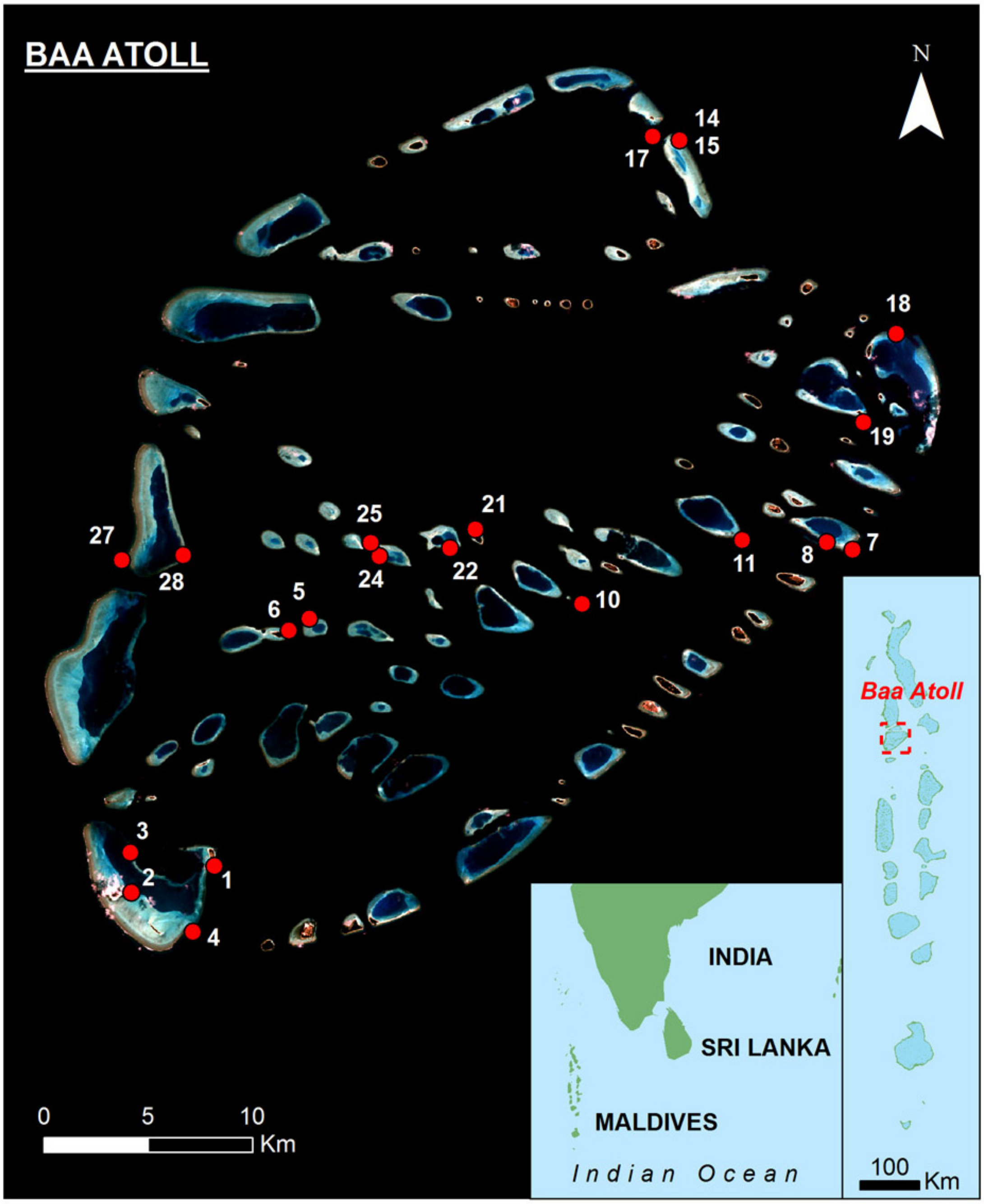

Figure 1. Location of the study area (Baa Atoll) in the Maldives and location of the sampling stations. According to reef geomorphology, the following biotopes were differentiated: lagoon reef flat (3, 8, 28), lagoon reef ridge (11), lagoon reef slope (1, 5, 6, 10, 19, 21, 22, 24, 25), outer reef flat (15), outer reef pass slope (4, 17), outer reef slope (7, 14, 18, 27) and seagrass flat (2).

RESULTS AND DISCUSSION

A total of 349 bony fish species (Osteichthyes) belonging to 46 families were recorded (Table 1, Plates 1- 3). Only one chondrichthyes (*Manta alfredi*) was observed during our sampling. Despite the extensive amount of time spent underwater, no shark was observed during our survey. Of the 350 species recorded, 30 species of small cryptic fish species were collected with clove oil. More than half of the recorded species (51.6%) belonged to six families: Labridae (47 sp, 13.4% of the total species), Pomacentridae (33 sp, 9.4%), Chaetodontidae (29 sp, 8.2%), Gobiidae (28 sp, 8%), Acanthuridae (24 sp, 6.9%) and Serranidae (20 sp, 5.7%). Only four stations provided a lower diversity than 100 species; they are located on shallow areas as seagrass flat (station 2) and reef flats (stations 3, 8 and 15). On the other hand, six stations situated on reef slopes (stations 10, 17, 19, 25 and 27) and outer reef ridge (station 11) yielded more than 130 species (Table 1). Some species were found only on specific biotopes: *Cheilio inermis, Calotomus carolinus, Leptoscarus vaigiensis, Pardachirus sp, Arothron hispidus and A. immaculatus* on seagrass flat, and *Lethrinus harak*, *Rhinecanthus aculeatus* and *R. rectangulus* on reef flat stations (stations 8 and 15). Five species are endemic to Maldives (1.4% of the total shore fish species recorded during the fieldtrip): the black-finned clownfish *Amphiprion nigripes* (Pomacentridae), the black-flag sandperch *Parapercis signata* (Pinguipedidae), the Maldivian triple-fin *Helcogramma larvata and Helcogramma maldivensis* (Tripterygiidae) and the comb-tooth blenny *Ecsenius minutus* (Blenniidae).

Comparison of the 350 fish species recorded at Baa Atoll during the present study with the species richness values recorded from other islands in the Indian Ocean revealed that Baa had one of the highest theoretic fish species richness recorded in the Indian Ocean region (Table 2). The Maldives belong to one of the eleven marine biodiversity hotspot regions identified on Earth, hotspot that encompasses the Maldives, Chagos islands and much of the Lakshadweep and Lakkadives archipelagoes as well as Sri Lanka. On the Southern hemisphere, Reunion island has also a high species richness compared to others islands of the Mascareignes archipelago (Rodrigues) and Mozambique Channel (Juan de Nova, Glorieuses, Geyser, Mayotte). This could be due to the higher sampling effort at the Reunion island since reef fish research is permanently conducted there since the 90's (eg. Letourneur, 1992; Chabanet, 1994) while in other areas inventories are conducted over a few weeks only.

These results indicate that the coral reefs of Baa Atoll have a high fish diversity, suggesting a relatively healthy system, keeping in mind its proximity to Asia and the "coral triangle" where diversity is maximum in the Indo-Pacific. However, some of the largest apex predators (Carangidae, Sphyraenidae, Lutjanidae) were rare. Notably, not a single shark (Carcharhinidae) was observed during the 10 days fish survey. Angling and shark fishing are likely the cause of such dramatic depopulation. In turn, parrotfishes (Scaridae) and surgeonfishes (Acanthuridae) were abundant and displayed sizes near their maximum lengths, while their behaviour was nearly unaffected by the presence of divers, which is typical for areas (usually MPAs) where spear and net fishing is prohibited.

Table 1. Inventory of the reef fishes of the Baa atoll, Maldives (from depths of 0-20 m) according to stations where they were sampled (UVC: underwater visual census, CO: clove oil, Ph: photo). The total number of species recorded by UVC is specify for each station at the end of the table. See Fig. 1 for the localisation of stations.

Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Myliobatidae																						
Manta alfredi (Krefft, 1868)	UVC									1	1											
Muraenidae																						
Gymnothorax berndti Snyder, 1904	UVC								1													
Gymnothorax breedeni McCosker & Randall, 1977	UVC							1														
Gymnothorax flavimarginatus (Rüppell, 1830)	UVC									1												
Gymnothorax javanicus (Bleeker, 1859)	UVC							1		1	1		1	1	1							
Gymnothorax undulatus (Lacepède, 1803)	UVC		1							1	1											
Synodontidae																						
Saurida gracilis (Quoy & Gaimard, 1824)	UVC	1		1	1	1		1						1		1	1					
Synodus binotatus Schultz in Schultz et al., 1953	CO							1														
Synodus variegatus (Lacepède, 1803)	UVC														1		1	1				
Atherinidae																						
Hypoatherina barnesi Schultz, 1953	UVC			1					1				1									1
Holocentridae																						
Myripristis adusta Bleeker, 1853	UVC							1			1	1		1							1	1
Myripristis berndti Jordan & Evermann, 1903	UVC	1		1	1	1	1	1			1			1	1	1	1	1	1	1	1	1
Myripristis kuntee Valenciennes in Cuvier & Valenciennes, 1831	UVC				1			1													1	
Myripristis pralinia Cuvier, 1829	UVC									1				1								
Myripristis violacea Bleeker, 1851	UVC			1	1	1	1	1			1							1	1	1	1	1
Myripristis vittata Valenciennes in Cuvier & Valenciennes, 1831	UVC							1									1					
Neoniphon sammara (Forsskål in Niebuhr, 1775)	UVC			1													1					1
Sargocentron caudimaculatum (Rüppell, 1838)	UVC	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Sargocentron diadema (Lacepède, 1802)	UVC				1			1	1				1								1	
Sargocentron spiniferum (Forsskål in Niebuhr, 1775)	UVC				1	1	1	1			1	1		1			1	1	1	1	1	
Sargocentron tiere (Cuvier in Cuvier & Valenciennes, 1829)	UVC							1														
Sargocentron violaceum (Bleeker, 1853)	UVC					1								1				1				
Aulostomidae																						
Aulostomus chinensis (Linnaeus, 1766)	UVC					1		1											1			1
Syngnathidae																						
Corythoichthys schultzi Herald in Schultz *et al*., 1953	UVC			1												1						1
Fistulariidae																						
Fistularia commersonii Rüppell, 1838	UVC									1												
Scorpaenidae																						
Pterois antennata (Bloch, 1787)	UVC	1					1												1			

Table 1 Con'td

Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Pterois miles (Bennett, 1828)	UVC				1					1				1								
Scorpaenodes parvipinnis (Garrett, 1863)	CO	1																				
Scorpaenodes varipinnis Smith, 1957	CO							1														
Scorpaenopsis diabolus (Cuvier, 1829)	UVC								1	1												
Scorpaenopsis oxycephala (Bleeker, 1849)	UVC									1		1										
Sebastapistes cyanostigma (Bleeker, 1856)	UVC												1									
Platycephalidae																						
Thysanophrys chiltonae Schultz in Schultz et al., 1966	CO														1							
Serranidae																						
Aethaloperca rogaa (Forsskål in Niebuhr, 1775)	UVC	1					1	1		1	1	1		1	1	1	1		1	1	1	
Anyperodon leucogrammicus (Cuvier in Cuvier & Valenciennes, 1828	UVC					1		1		1				1			1	1	1			1
Cephalopholis argus Bloch & Schneider, 1801	UVC	1		1	1	1	1	1		1		1		1	1	1	1	1	1	1	1	1
Cephalopholis leopardus (Lacepède, 1801)	UVC	1			1	1	1	1		1	1	1		1	1		1	1	1	1	1	1
Cephalopholis miniata (Forsskål in Niebuhr, 1775)	UVC					1	1			1	1	1		1	1	1					1	
Cephalopholis sexmaculata (Rüppell, 1830)	UVC	1					1			1	1	1		1		1					1	
Cephalopholis urodeta (Bloch & Schneider, 1801)	UVC	1								1	1				1	1				1	1	
Epinephelus merra Bloch, 1793	UVC				1				1										1	1		1
Epinephelus oceanicus (Lacepède, 1802)	UVC	1																			1	
Epinephelus polyphekadion (Bleeker, 1849)	UVC										1			1					1			
Epinephelus spilotoceps Schultz in Schultz *et al*., 1953	UVC	1			1		1	1						1	1	1	1				1	
Epinephelus tauvina (Forsskål in Niebuhr, 1775)	UVC											1										
Gracila albomarginata (Fowler & Bean, 1930)	UVC					1	1															
Grammistes sexlineatus (Thunberg, 1792)	UVC													1								
Plectropomus laevis (Lacepède, 1801)	UVC	1				1	1			1				1		1	1					1
Pseudanthias evansi (Smith, 1954)	UVC	1					1	1				1		1	1		1		1			
Pseudanthias ignitus (Randall & Lubbock, 1981)	UVC							1						1							1	
Pseudanthias squamipinnis (Peters, 1855)	UVC	1			1		1	1		1	1	1		1	1	1	1				1	
Pseudogramma polyacantha (Bleeker, 1856)	CO							1														
Variola louti (Forsskål, 1775)	UVC	1			1	1	1		1					1	1	1	1	1	1	1	1	1
Pseudochromidae																						
Chlidichthys inornatus Lubbock, 1976	CO							1				1										1
Plesiopidae																						
Calloplesiops altivelis (Steindachner, 1903)	UVC	1																	1			
Priacanthidae																						
Priacanthus hamrur (Forsskål in Niebuhr, 1775)	UVC					1																
Apogonidae																						

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Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Apogon cf. *chrysotaenia* Bleeker, 1851	UVC															1						
Apogon doryssa (Jordan & Seale, 1906)	CO							1														
Apogon fleurieu (Lacepède, 1802)	CO							1														
Apogon cookii Macleay, 1881	UVC				1					1				1		1				1		
Cheilodipterus artus Smith, 1961	UVC						1	1						1			1		1			
Cheilodipterus isostigmus (Schultz, 1940)	UVC					1								1					1			
Cheilodipterus lineatus (Lacepède, 1801)	UVC					1											1					
Cheilodipterus quinquelineatus Cuvier in Cuvier & Valenciennes, 182	UVC													1								
Ostorhinchus angustatus (Smith & Radcliffe in Radcliffe, 1911)	UVC						1				1											
Osrorhinchus nigrofasciatus (Lachner, 1953)	UVC/CO						1	1	1			1		1	1	1	1	1	1			
Ostorhinchus novemfasciatus (Cuvier in Cuvier & Valenciennes, 1828	CO								1													
Pristiapogon fraenatus (Valenciennes, 1832)	UVC	1																				
Pristiapogon kallopterus (Bleeker, 1856)	UVC														1	1						
Pristiapogon taeniopterus (Bennett, 1836)	UVC													1								
Apogon sp.									1													
Malacanthidae																						
Malacanthus latovittatus (Lacepède, 1801)	UVC														1	1					1	
Carangidae																						
Carangoides ferdau (Forsskål in Niebuhr, 1775)	UVC								1													
Caranx ignobilis (Forsskål in Niebuhr, 1775)	UVC									1	1											
Caranx melampygus Cuvier in Cuvier & Valenciennes, 1833	UVC									1	1	1									1	1
Lutjanidae																						
Aphareus furca (Lacepède, 1801)	UVC	1		1			1	1		1	1	1		1				1	1	1	1	1
Aprion virescens Valenciennes in Cuvier & Valenciennes, 1830	UVC					1	1				1	1						1			1	
Lutjnanus biguttatus (Valenciennes in Cuvier & Valenciennes, 1830)	UVC																1	1	1			
Lutjanus bohar (Forsskål in Niebuhr, 1775)	UVC	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Lutjanus gibbus (Forsskål in Niebuhr, 1775)	UVC		1		1	1			1			1		1		1	1	1	1			1
Lutjanus *kasmira* (Forsskål in Niebuhr, 1775)	UVC					1	1			1							1		1		1	1
Lutjanus monostigma (Cuvier in Cuvier & Valenciennes, 1828)	UVC									1	1			1		1						1
Macolor macularis Fowler, 1931	UVC				1	1		1		1		1		1		1					1	
Macolor niger (Forsskål in Niebuhr, 1775)	UVC			1	1	1				1	1			1			1	1	1	1		
Caesionidae																						
Caesio lunaris Cuvier in Cuvier & Valenciennes, 1830	UVC											1										1
Caesio xanthonota Bleeker, 1853	UVC	1								1												
Pterocaesio chrysozona (Cuvier in Cuvier & Valenciennes, 1830)	UVC											1										
Pterocaesio marri Schultz in Schultz *et al* ., 1953	UVC																	1				

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Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Pterocaesio pisang (Bleeker, 1853)	UVC					1					1			1	1	1				1		
Pterocaesio tile (Cuvier in Cuvier & Valenciennes, 1830)	UVC	1				1	1	1		1	1	1		1		1			1	1		
Pterocaesio trilineata Carpenter, 1987	UVC	1					1												1	1		
Haemulidae																						
Plectorhinchus chaetodonoides Lacepède, 1801	UVC													1								
Plectorhinchus obscurus (Günther, 1872)	UVC														1							
Plectorhinchus vittatus (Linnaeus, 1758)	UVC			1		1	1	1		1	1		1	1			1		1	1	1	1
Lethrinidae																						
Gnathodentex aureolineatus (Lacepède, 1802)	UVC			1				1										1		1	1	
Lethrinus harak (Forsskål in Niebuhr, 1775)	UVC								1													
Lethrinus olivaceus Valenciennes in Cuvier & Valenciennes, 1830	UVC																				1	
Lethrinus xanthochilus Klunzinger, 1870	UVC															1					1	1
Lethrinus sp.	UVC		1																			
Monotaxis grandoculis (Forsskål in Niebuhr, 1775)	UVC	1		1		1	1	1		1	1				1	1	1	1	1	1	1	1
Nemipteridae																						
Scolopsis aurata (Park, 1797)	UVC						1															
Scolopsis bilineata (Bloch, 1793)	UVC	1		1	1	1	1	1		1	1			1	1	1		1	1	1	1	1
Mullidae																						
Mulloidichthys flavolineatus (Lacepède, 1801)	UVC			1		1											1					
Parupeneus barberinus (Lacepède, 1801)	UVC	1		1	1	1	1		1	1		1	1		1	1			1	1		1
Parupeneus cyclostomus (Lacepède, 1801)	UVC	1		1	1	1			1	1				1	1	1		1	1		1	1
Parupeneus macronemus (Lacepède, 1801)	UVC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Parupeneus pleurostigma (Bennett, 1831)	UVC	1								1	1									1		
Parupeneus trifasciatus (Lacepède, 1801)	UVC	1		1	1		1	1	1				1		1						1	1
Pempheridae																						
Parapriacanthus ransonneti Steindachner, 1870	UVC	1																			1	
Kyphosidae																						
Kyphosus vaigiensis (Quoy & Gaimard, 1825)	UVC																					1
Chaetodontidae																						
Chaetodon auriga Forsskål in Niebuhr, 1775	UVC	1		1				1				1	1			1	1	1	1	1	1	1
Chaetodon bennetti Cuvier, 1831	UVC																		1			
Chaetodon citrinellus Cuvier, 1831	UVC	1		1	1				1				1								1	1
Chaetodon collare Bloch, 1787	UVC	1		1	1			1			1	1		1	1	1	1	1			1	1
Chaetodon decussatus Cuvier, 1829	UVC				1																	
Chaetodon falcula Bloch, 1795	UVC	1		1		1	1			1	1	1		1	1		1	1	1	1	1	1
Chaetodon guttatissimus Bennett, 1833	UVC	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

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Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Amblyglyphidodon batunai Allen, 1995	UVC																		1			
Amphiprion clarkii (Bennett, 1830)	UVC					1	1	1		1	1	1		1	1	1		1		1	1	
Amphiprion nigripes Regan, 1908	UVC						1			1						1				1		
Chromis agilis Smith, 1960	UVC																1	1				
Chromis atripectoralis Welander & Schultz, 1951	UVC			1		1	1			1		1		1		1	1	1	1	1		1
Chromis dimidiata (Klunzinger, 1871)	UVC	1			1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Chromis flavipectoralis Randall, 1988	UVC	1				1	1											1	1			
Chromis lepidolepis Bleeker, 1877	UVC													1								
Chromis nigrura Smith, 1960	UVC												1									
Chromis opercularis (Günther, 1867)	UVC	1			1	1				1		1				1	1				1	1
Chromis ternatensis (Bleeker, 1856)	UVC	1				1	1	1		1		1		1	1	1	1	1	1	1		1
Chromis viridis Cuvier in Cuvier & Valenciennes, 1830	UVC	1		1	1	1	1							1	1	1		1	1			1
Chromis weberi Fowler & Bean, 1928	UVC				1			1		1	1	1			1	1					1	
Chromis xutha Randall, 1988	UVC	1				1	1	1				1	1	1	1				1	1		
Chrysiptera brownriggii (Bennett, 1828)	UVC												1									
Chrysiptera glauca (Cuvier in Cuvier & Valenciennes, 1830)	UVC								1													
Chrysiptera unimaculata (Cuvier in Cuvier & Valenciennes, 1830)	UVC								1				1									
Dascyllus aruanus (Linnaeus, 1758)	UVC	1		1		1	1	1						1		1	1	1	1	1		1
Dascyllus carneus Fischer, 1885	UVC	1			1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Dascyllus trimaculatus (Rüppell, 1829)	UVC	1	1							1	1	1		1	1	1	1	1		1	1	
Lepidozygus tapeinosoma (Bleeker, 1856)	UVC										1					1					1	
Plectroglyphidodon dickii (Liénard, 1839)	UVC										1											1
Plectroglyphidodon lacrymatus (Quoy & Gaimard, 1825)	UVC	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Pomacentrus caeruleus Quoy & Gaimard, 1825	UVC	1				1	1			1	1	1				1	1	1	1	1	1	
Pomacentrus chrysurus Cuvier in Cuvier & Valenciennes, 1830	UVC		1	1	1			1	1	1	1	1	1	1	1	1	1	1		1	1	1
Pomacentrus indicus Allen, 1991	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Pomacentrus nagasakiensis Tanaka, 1917	UVC									1					1	1	1	1				
Pomacentrus pavo (Bloch, 1787)	UVC	1		1		1				1				1		1		1	1	1		1
Pomacentrus philippinus Evermann & Seale, 1907	UVC	1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1
Stegastes fasciolatus (Ogilby, 1889)	UVC								1													
Stegastes nigricans (Lacepède, 1802)	UVC			1																		1
Labridae																						
Anampses caeruleopunctatus Rüppell, 1829	UVC																	1				
Anampses meleagrides Valenciennes in Cuvier & Valenciennes, 1840	UVC	1			1	1				1	1				1	1				1	1	
Bodianus axillaris (Bennett, 1832)	UVC	1		1	1	1	1	1		1	1				1	1	1				1	1
Bodianus bilunulatus (Lacepède, 1801)	UVC																			1		

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Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Bodianus diana (Lacepède, 1801)	UVC				1			1		1	1	1		1	1	1					1	
Cheilinus chlorourus (Bloch, 1791)	UVC	1	1		1		1		1				1						1			1
Cheilinus fasciatus (Bloch, 1791)	UVC					1	1			1						1		1	1	1		1
Cheilinus oxycephalus Bleeker, 1853	UVC																	1				1
Cheilinus trilobatus Lacepède, 1801	UVC		1	1					1				1							1		1
Cheilinus undulatus Rüppell, 1835	UVC			1				1							1							
Cheilio inermis (Forsskål in Niebuhr, 1775)	UVC		1																			
Coris cuvieri (Bennett, 1831)	UVC	1			1					1	1			1		1					1	
Coris frerei (Günther in Playfair & Günther, 1867)	UVC								1						1						1	
Coris batuensis (Bleeker, 1856)	UVC	1				1	1								1	1			1	1		1
Cymolutes praetextatus (Quoy & Gaimard, 1834)	UVC								1													
Cirrhilabrus exquisitus Smith, 1957	UVC	1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1
Epibulus insidiator (Pallas, 1770)	UVC	1		1		1	1	1						1					1			1
Gomphosus caeruleus Lacepède, 1801	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Halichoeres cosmetus Randall & Smith, 1982	UVC				1	1		1	1	1	1	1		1	1	1		1			1	
Halichoeres hortulanus (Lacepède, 1801)	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Halichoeres lamarii Cuvier & Valenciennes, 1839	UVC		1	1		1							1			1		1	1	1		1
Halichoeres leucoxanthus Randall & Smith, 1982	UVC	1		1						1		1				1					1	
Halichoeres nebulosus (Valenciennes in Cuvier & Valenciennes, 1839	UVC		1						1				1									
Halichoeres scapularis (Bennett, 1832)	UVC		1	1					1					1		1		1			1	1
Halichoeres trispilus Randall & Smith, 1982	UVC													1				1	1	1		
Halichoeres vrolikii (Bleeker, 1855)	UVC	1		1		1	1			1	1			1			1	1	1	1		1
Hemigymnus fasciatus (Bloch, 1792)	UVC	1		1		1	1	1		1	1	1		1	1	1	1	1	1	1		1
Hemigymnus melapterus (Bloch, 1791)	UVC	1		1				1			1				1		1	1		1		1
Hologymnosus annulatus (Lacepède, 1801)	UVC	1				1				1											1	
Labroides bicolor Fowler & Bean, 1928	UVC	1		1	1	1	1	1		1		1		1	1		1	1	1	1	1	1
Labroides dimidiatus (Valenciennes in Cuvier & Valenciennes, 1839)	UVC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Labrichthys unilineatus (Guichenot, 1847)	UVC	1		1		1	1	1		1	1			1	1		1			1		1
Macropharyngodon bipartitus Smith, 1957	UVC	1			1	1		1		1	1	1	1		1	1				1	1	
Novaculichthys taeniourus (Lacepède, 1801)	UVC	1							1													
Oxycheilinus bimaculatus (Valenciennes in Cuvier & Valenciennes, 18	UVC																	1				
Oxycheilinus digrammus (Lacepède, 1801)	UVC	1				1	1	1		1	1			1	1		1	1	1	1		1
Pseudocheilinus evanidus Jenkins, 1901	UVC				1																	
Pseudocheilinus hexataenia (Bleeker, 1857)	UVC	1		1		1	1	1		1	1	1		1	1	1	1	1	1	1	1	1
Pseudodax moluccanus (Valenciennes in Cuvier & Valenciennes, 184	UVC					1		1			1	1				1					1	1
Stethojulis albovittata (Bonnaterre, 1788)	UVC	1	1	1	1			1	1			1	1	1	1		1	1		1	1	1

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Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Ecsenius midas Starck, 1969	UVC																				1	
Ecsenius minutus Klausewitz, 1963	UVC	1			1	1	1	1	1		1	1	1	1			1	1	1	1	1	
Meiacanthus smithi Klausewitz, 1962	UVC			1				1										1				
Plagiotremus phenax Smith-Vaniz, 1976	UVC					1								1								
Plagiotremus rhinorhynchos (Bleeker, 1852)	UVC				1		1			1	1	1	1	1	1	1		1			1	
Salarias fasciatus (Bloch, 1786)	UVC												1									
Gobiidae																						
Amblyeleotris steinitzi (Klausewiz, 1974)	UVC															1						
Amblyeleotris sp.	UVC										1					1						
Amblygobius hectori (Smith, 1957)	UVC					1	1										1	1				
Amblygobius semicinctus (Bennett, 1833)	UVC/CO		1																			1
Bryaninops erythrops (Jordan & Seale, 1906)	CO	1																				
Bryaninops natans Larson, 1985	UVC						1	1		1	1			1					1	1	1	
Bryaninops tigris Larson, 1985	PH											1										
Ctenogobiops crocineus Smith, 1959	CO																1					
Eviota albolineata Jewett & Lachner, 1983	CO							1														
Eviota guttata Lachner & Karnella, 1978	UVC/CO			1			1	1			1	1		1				1	1	1		1
Eviota nebulosa Smith, 1958	CO							1														
Eviota nigriventris Giltay, 1933	CO																1					
Eviota sebreei Jordan & Seale, 1906	CO											1					1					
Eviota zebrina Lachner & Karnella, 1978	UVC/CC	1												1				1		1		
Fusigobius duospilus Hoese & Reader, 1985	UVC											1								1		
Fusigobius neophytus (Günther, 1877)	UVC/CC	1	1		1	1							1		1		1			1	1	1
Gnatholepis anjerensis (Bleeker, 1851)	UVC															1						
Gnatholepis cauerensis (Bleeker, 1853)	UVC/CO		1												1		1			1	1	1
Gobiodon rivulatus (Rüppell, 1830)	CO																			1		
Gobiodon unicolor (Castelnau, 1873)	CO																			1		
Istigobius decoratus (Herre, 1927)	UVC															1					1	
Paragobiodon xanthosomus (Bleeker, 1852)	CO																1			1		1
Pleurosicya mossambica Smith, 1959	CO														1							
Trimma flammeum (Smith, 1959)	CO	1						1				1					1					1
Trimma haima Winterbottom, 1984	CO	1																				
Trimma taylori Lobel, 1979	CO	1				1																
Trimma *tevegae* Cohen & Davis, 1969	UVC						1			1	1			1			1	1	1		1	

Table 1 Con'td

Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Valenciennea strigata (Broussonet, 1782)	UVC								1												1	
Microdesmidae																						
Nemateleotris magnifica Fowler, 1938	UVC				1			1			1				1						1	
Ptereleotris evides (Jordan & Hubbs, 1925)	UVC	1			1		1	1			1	1		1	1	1		1		1	1	1
Ephipiidae																						
Platax orbicularis (Forsskål in Niebuhr, 1775)	UVC										1											
Siganidae																						
Siganus argenteus (Quoy & Gaimard, 1825)	UVC		1																	1		1
Siganus corallinus (Valenciennes in Cuvier & Valenciennes, 1835)	UVC																		1			1
Siganus puelloides Woodland & Randall, 1979	UVC					1		1												1		
Siganus stellatus (Forsskål in Niebuhr, 1775)	UVC	1						1				1		1		1	1		1	1	1	
Zanclidae																						
Zanclus cornutus (Linnaeus, 1758)	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Acanthuridae																						
Acanthurus auranticavus Randall, 1956	UVC			1	1			1	1													
Acanthurus bariene Lesson, 1831	UVC										1					1						
Acanthurus leucocheilus Herre, 1927	UVC	1		1	1		1	1							1						1	
Acanthurus leucosternon Bennett, 1833	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Acanthurus lineatus (Linnaeus, 1758)	UVC			1					1				1									1
Acanthurus mata Russell in Cuvier, 1829	UVC					1	1							1				1	1	1	1	
Acanthurus nigricauda Duncker & Mohr, 1929	UVC	1		1	1		1	1	1	1	1	1	1		1	1	1			1	1	
Acanthurus nigrofuscus (Forsskål in Niebuhr, 1775)	UVC				1				1		1		1							1	1	1
Acanthurus tennentii Günther, 1861	UVC				1				1				1	1								1
Acanthurus thompsoni (Fowler, 1923)	UVC	1				1	1			1	1	1		1	1	1	1	1	1	1	1	1
Acanthurus triostegus (Linnaeus, 1758)	UVC								1				1							1		
Acanthurus tristis Randall, 1993	UVC									1					1							
Ctenochaetus binotatus Randall, 1955	UVC	1		1	1	1	1			1	1	1			1						1	1
Ctenochaetus striatus (Quoy & Gaimard, 1825)	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ctenochaetus strigosus (Bennett, 1828)	UVC	1			1	1	1	1			1	1		1	1	1	1	1	1	1	1	
Naso brachycentron (Valenciennes in Cuvier & Valenciennes, 1835)	UVC																	1	1			
Naso brevirostris (Cuvier, 1829)	UVC	1		1	1		1	1		1	1	1				1		1	1	1	1	1
Naso elegans (Rüppell, 1829)	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Naso hexacanthus (Bleeker, 1855)	UVC	1		1	1	1	1	1		1	1	1		1		1	1		1	1	1	
Naso thynnoides (Valenciennes in Cuvier & Valenciennes, 1835)	UVC	1						1				1									1	
Naso unicornis (Forsskål in Niebuhr, 1775)	UVC								1					1				1		1		
Naso vlamingi (Valenciennes, 1835)	UVC	1				1	1			1	1			1	1	1	1	1	1	1	1	
Zebrasoma scopas (Cuvier, 1829)	UVC	1		1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	1

Table 1 Con'td

Families - Species - Authors / stations		1	2	3	4	5	6	7	8	10	11	14	15	17	18	19	21	22	24	25	27	28
Zebrasoma velifer (Bloch, 1795)	UVC			1	1						1	1		1	1	1	1	1	1	1	1	1
Scombridae																						
Gymnosarda unicolor (Rüppell, 1836)	UVC				1		1			1				1	1			1	1			
Soleidae																						
Aseraggodes xenicus (Matsubara & Ochiai, 1963)	CO								1													
Pardachirus sp.	UVC		1																			
Balistidae																						
Balistapus undulatus (Park, 1797)	UVC	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Balistoides conspicillum (Bloch & Schneider, 1801)	UVC	1			1		1	1		1	1	1		1	1	1	1	1		1	1	1
Balistoides viridescens (Lacepède, 1801)	UVC	1			1	1		1		1	1	1			1	1			1	1		
Melichthys indicus Randall & Klausewitz, 1973	UVC	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Odonus niger (Rüppell, 1836)	UVC	1			1			1		1	1	1		1	1	1				1	1	
Pseudobalistes flavimarginatus (Rüppell, 1829)	UVC		1			1						1		1	1	1				1	1	
Rhinecanthus aculeatus (Linnaeus, 1758)	UVC								1													
Rhinecanthus rectangulus (Lacepède in Bloch & Schneider, 1801)	UVC								1				1									
Sufflamen bursa (Lacepède in Bloch & Schneider, 1801)	UVC	1			1	1	1	1		1	1	1	1	1	1		1			1	1	
Sufflamen chrysopterum (Bloch & Schneider, 1801)	UVC		1	1	1	1	1		1	1			1		1	1				1	1	1
Aluteres scriptus (Osbeck, 1765)	UVC									1		1								1		
Amanses scopas (Cuvier, 1829)	UVC	1			1	1	1	1													1	
Cantherhines dumerilii (Hollard, 1854)	UVC																				1	
Cantherhines pardalis (Rüppell, 1837)	UVC	1	1	1	1				1	1	1		1			1		1	1	1	1	1
Pervagor aspricaudus (Hollard, 1854)	UVC													1						1		
Pervagor janthinosoma (Bleeker, 1854)	UVC				1		1															
Ostraciidae																						
Ostracion cubicus Linnaeus, 1758	UVC													1							1	
Ostracion meleagris Shaw in Shaw & Nodder, 1796	UVC					1	1	1		1	1								1			
Tetraodontidae																						
Arothron hispidus (Linnaeus, 1758)	UVC		1																			
Arothron immaculatus (Bloch & Schneider, 1801)	UVC		1																			
Arothron meleagris (Anonymus, 1798)	UVC					1																
Arothron nigropunctatus (Bloch & Schneider, 1801)	UVC										1				1		1	1	1			
Canthigaster amboinensis (Bleeker, 1865)	UVC									1										1		
Canthigaster bennetti (Bleeker, 1854)	UVC			1					1							1						
Canthigaster janthinoptera (Bleeker, 1855)	UVC																					1
Canthigaster valentini (Bleeker, 1853)	UVC	1		1	1	1	1	1		1	1			1	1	1	1	1		1		1
Diodontidae																						
Diodon liturosus Shaw, 1804	UVC							1			1						1			1		
Total number of species	UVC	124	31	94	108	119	117	123	67	133	131	114	59	134	116	130	108	116	120	130	139	126

Table 2. Species richness (SR) of fish communities on Indian Ocean coral reefs. SR$_{obs}$: observed SR; SR$_{th}$: theoretic SR calculated from CFDI (Coral Fish Diversity Index) according to Allen & Werner formula (2002). GC: geographic coordinates. *: underwater visual census (UVC) (0-20 m), **: fishing methods, ***: UVC, rotenone, fishing, museum and literature records.

Sites	GC	References	RS obs	RS th
Maldives	7°N-1°S, 72°-74°E	Randall and Anderson, 1993	899	671
Baa (Maldives)*^{co}	5°N and 73°E	This study	333	505
Juan de Nova*	17°S, 42°E	Chabanet and Durville, 2005	299	423
Glorieuses*	11°S, 47°E	Durville et al., 2003	347	468
Geyser*	12°S, 46E	Chabanet et al., 2002	294	433
Mayotte*	13°S, 45°E	Letourneur, 1996; Chabanet, 2002	239	423
Reunion***	21°S, 55°E	Fricke et al., 2009	549	596
Rodrigues***	20°S, 62°E	Heemstra et al., 2004	410	493

ACKNOWLEDGEMENTS

Acknowledgements to Loreen R. O'Hara of Bishop Museum (Hawaii) for sending the data (from Randall & Anderson, 1993) necessary to calculate coral fish diversity index of the Maldives. This study was funded by the French Fondation pour la Recherche sur la Biodiversité, Program "Biodiversity of Indian Ocean Islands", and by the Atoll Ecosystem Conservation Project. We acknowledge Shiham Adam and Hussain Zahir at the Marine Research Center for the help in organizing this survey.

REFERENCES

Adam, M. S.
1995. Review of the aquarium fish trade of the Maldives with proposals of monitoring and regulation of the trade. Malé (Marine Research Station), p. 1-35.
Adam, M. S.
2006. Vulnerability and adaptation assessment of the fisheries sector in the Maldives - NAPA Project. Malé (Ministry of Environment, Energy and Water), p. 1-32.
Adam, M. S., and G.P. Kirkwood
2001. Estimating tag-shedding rates for skipjack tuna, *Katsuwonus pelamis*, off the Maldives. *Fishery Bulletin* 99: 193-196.
Adam, M. S., and A.R. Jauharee
2009. Handline large yellowfin tuna fishery of the Maldives. Indian Ocean Tuna

Commission, 10th Session of the Working Party on Tropical Tunas, Mombasa, Kenya, 15-23 October 2009: 1-14.

Allen, G. R., and T. B. Werner
2002. Coral reef fish assessment in the 'coral triangle' of southeastern Asia. *Environmental Biology of Fishes* 65: 209–214.

Anderson, R. C.
2005. Reef Fishes of the Maldives. Manta Marine, Malé, 136 pp.

Anderson, R. C., and H. Ahmed
1993. The shark fisheries in the Maldives. Malé (MOFA), Rome (FAO), p. 1-73.

Anderson, R. C., and A. Hafiz
1984. Livebait fishes of the Maldives. *Rasain* 4: 187-192.

Anderson, R. C., Z. Waheed, and M. S. Adam
1998. The tuna fishery resources of the Maldives. *Maldives Marine Research Bulletin* 3: 1-180.

Chabanet, P.
1994. Etude des relations entre les peuplements ichtyologiques et les peuplements benthiques sur le complexe récifal de St-Gilles/ La Saline (Ile de La Réunion). Thèse Doctorat Université Aix-Marseille III, 263 p.

Chabanet, P.
2002. Coral reef fish communities of Mayotte (western Indian Ocean) two years after the impact of the 1998 bleaching event. *Marine & Freshwater Research* 53: 107-113.

Chabanet, P., E. Tessier, P. Durville, T. Mulochau, and F. René
2002. Peuplement ichtyologique des bancs de Geyser et Zélée (Océan Indien Occidentale). *Cybium* 26: 11-26.

Chabanet, P., and P. Durville
2005. Reef fish inventory of Juan de Nova's Natural Park (Western Indian Ocean). *Western Indian Ocean Journal of Marine Science* 4: 145 -162.

Durville, P., P. Chabanet, and J-P. Quod
2003. Visual census of the reef fishes in the natural reserve of the Glorieuses Islands (Western Indian Ocean). *Western Indian Ocean Journal of Marine Science* 2: 95-104.

Fricke, R., Mulochau T., Durville P., Chabanet P., Tessier E. and Letourneur Y.
2009. Annotated checklist of the fish species (Pisces) of La Réunion, including a Red List of threatened and declining species. *Stuttgarter Beiträge zur Naturkunde* (A) Neue Serie 2: 1-168.

Heemstra, E., P. C. Heemstra, M. J. Smale, T. Hooper and D. Pelicier
2004. Preliminary checklist of coastal fishes from the Mauritian island of Rodrigues. *Journal of Natural History* 38: 3315-3344.

Kent, G.
1997. Fisheries, food security and the poor. *Food Policy* 22: 393-404.

Letourneur, Y.
1992. Dynamique des peuplements ichtyologiques des platiers récifaux de l'Ile de La Réunion. Thèse Doctorat Université Aix-Marseille II, 244 p.

Letourneur, Y.

1996. Réponse des peuplements et populations de poissons aux réserves marines: le cas de l'île de Mayotte, Océan Indien occidental. *Ecoscience* 3: 442–450.

Martin, R. A., and A. A. Hakeem

2006. Development of a sustainable shark diving ecotourism industry in the Maldives: challenges and opportunities. *Maldives Marine Research Bulletin* 8: 2-38.

McClanahan, T. R.

2011. Comparing coral reef fish communities in urban fisheries closures and "sustainable seascapes": Kenya *vs*. Maldives. *Aquatic Conservation: Marine and Freshwater Ecosystems* 21 : 186-198.

MRS

1996. The Maldivian tuna fishery: a collection of tuna resource research papers. *Maldives Marine Research Bulletin* 2: 1-176.

Newton, K., I. Côté, G. M. Pilling, S. Jenning, and N. K. Dulvy

2007. Current and future sustainability of island coral reef fisheries. *Current Biology* 17: 655-658.

Randall, J. E. and C. Anderson

1993. Annotated checklist of the epipelagic and shore fishes of the Maldives Islands. *Ichthyological Bulletin, J. L. B. Smith Institute of Ichthyology* 59: 1-47, pls. 1-8.

Risk, M. J., and B. Sluka

2000. The Maldives. In: T. R. McClanahan, C. R. C. Sheppard and D. O. Obura (eds.). Coral reefs of the Indian Ocean: Their ecology and conservation. Oxford University Press, NY.

Sattar, S. A., and M. S. Adam

2005. Review of grouper fishery of the Maldives with additional notes on the Faafu Atoll fishery. Malé (Marine Research Centre), p. 1-64.

Saleem, M. R., and Adam M. S.

2004. Review of aquarium fishery of the Maldives. Malé (Marine Research Station), p. 1-33.

Sluka, R. D., and M. W. Miller

2001. Herbivorous fish assemblages and herbivory pressure on Laamu Atoll, Republic of Maldives. *Coral Reefs* 20: 255-262.

Werner, T. B., and Allen G. R.

1998. A rapid biodiversity assessment of the coral reefs of Milne Bay Province, Papua New Guinea. *RAP Working Papers, Conservation International, Washington DC* 11: 1-109.

Plate 1: fish species photographed in situ (photos: Hani Amir, Serge Andréfouët)

Ecsenius minutus

Helcogramma maldivensis and *Ecsenius minutus*

Amphiprion clarkii (juvenile)

Chaetodon collare

Odonus niger

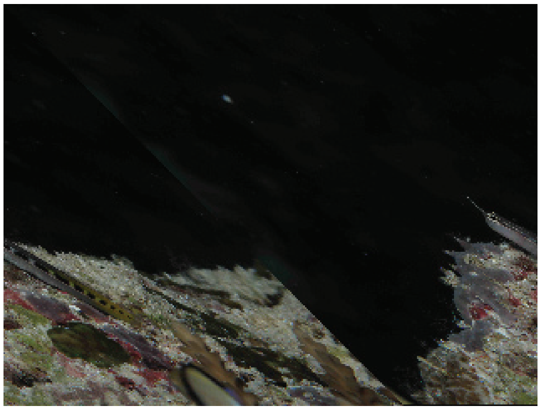
. Sargocentron spiniferum

Plate 2: fish species photographed in situ (photos: Hani Amir, Serge Andréfouët)

Mixed school of parrotfish including *Scarus rubroviolaceus, S. prasiognathus, S. frenatus* and *Chlorurus strongylocephalus*

Caranx melampygus

Bryaninops tigris

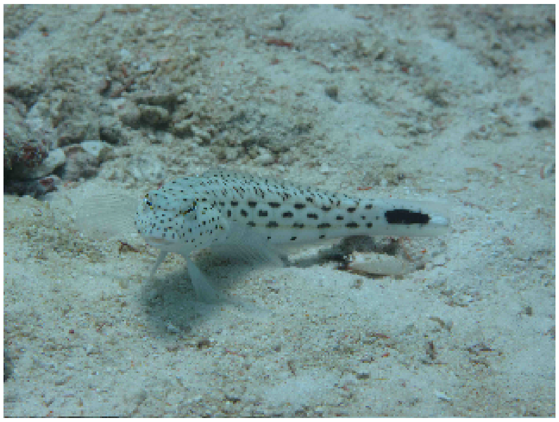


Ecsenius lineatus

Helcogramma maldivensis (endemic)

Paracirrhites forsteri

Plate 3: fish species photographed in situ (photos: Hani Amir, Serge Andréfouët)

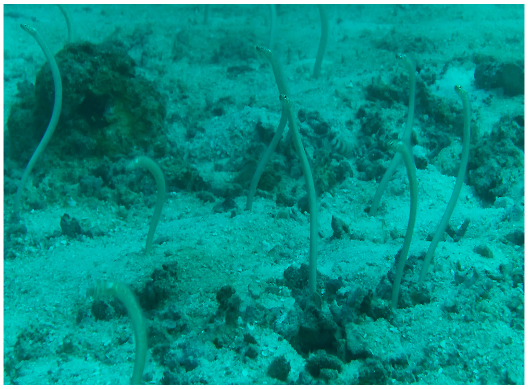


Parapercis hexophthalma

Parapercis signata (endemic)

Pseudanthias squamipinnis

Scorpaenopsis oxycephala



Gorgasia maculata

Manta alfredi (bottom), Platax orbicularis (top)

STATUS OF THE CORAL REEF FISHERY IN AN ATOLL COUNTRY UNDER TOURISM DEVELOPMENT: THE CASE OF CENTRAL MALDIVES

BY

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ABSTRACT

Fishing trips made in Central Maldives in 2006-2007 provided fresh insights on the status of the Republic of Maldives coral reef fishery. Previous assessments had been made nearly two decades prior and an update on the resource status was needed. Indeed, tourist resorts have multiplied in Maldives in the past 20 years, resulting in an increased demand for local fresh fish that resorts routinely purchase directly from local fishermen. To assess the impacts of tourism demand on fishery and fish populations, fishing locations, fishing gears, catch compositions and catch lengths are reported here for atolls of the Central Maldives. Data from the 2006-2007 fishing trips are compared to data available from Malé fish markets and to historical 1989/1991 fishing campaign data to assess potential changes in fish population structures and catches. Despite different sampling strategies, comparisons of catch data do not suggest any alarming trend. Catch composition is similar, and the most frequent species captured remain of similar sizes. Yields per square kilometre of fished reefs (1.7-3.5 tonnes/km^2) remain below published thresholds for unsustainable fisheries. Nevertheless, signs of changes should be taken seriously in the perspective of increased demand from the local tourism industry and increased value of fresh and processed fish for export markets.

INTRODUCTION

The Republic of Maldives is a tuna fishing nation. The tuna fishery was and still is the most important fishery, providing the main source of dietary protein plus visible export earnings that play a major role in the Maldivian economy (Department of National Planning, 2010). The traditional reef fishery was historically less important, and carried out in the Maldives for the purpose of local consumption typically at times when tuna catches were low. However, following the tourism industry development of the past decades, the reef fishery has expanded in volume and diversity over the years. A

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separate export-oriented grouper fishery was initiated in 1994 to target South-East Asian markets in the form of both fresh/chilled and live exports (Shakeel and Ahmed 1996; Sattar and Adam 2005). Tourism and the export industry (specifically for groupers) have likely changed reef fishery activities and resource status, but the picture remains unclear due to lack of continuous assessment and monitoring. Furthermore, tourism development and resort densities are uneven from one atoll to another and some atolls are likely more affected than others, especially in Central Maldives where resorts have been present for a long time.

Historically, two comprehensive surveys of the reef fishery were undertaken in 1988/1989 and 1990/1991 (Van Der Knaap et al., 1991; Anderson et al*.,* 1992). Anderson et al. (1992) details the catch composition based on long-line and hand-line fishing in lagoons, shallow reefs (<50 m) and deep oceanic slopes off Shaviyani, Alifu and Laamu atolls, respectively in North, Central and South Maldives. Van Der Knaap et al. (1991) reported on Male' atoll only, in Central Maldives. These previous studies focused on finfish for food consumption, and do not report on sea cucumbers, clams, lobsters, coral, turtle, baitfish, sharks or aquarium fish fisheries which have represented other important aspect of the Maldivian reef fishery, with varying intensities, throughout past decades (Anderson and Ahmed, 1993; Anderson, 1997; Ahmed et al*.,* 1997; Saleem and Adam, 2004; MRC, 2009).

A major result of these past surveys was the estimation for the entire Maldives of a maximum potential yield of 30,000 ± 13,000 tonnes/year for commercial reef fish (Anderson et al*.,* 1992). These estimates were based on a number of considerations: yields from different habitats (lagoon, reefs and deep oceanic slopes); distinct fishing methods; the surface areas of Maldivian atolls estimated from marine charts; statistical relationships between fishing yields and abundance-biomass data obtained from fisheries and underwater surveys from other regions such as the lagoons of New-Caledonia (Anderson et al., 1992; Kulbicki, 1988). The suite of caveats and limitations for such computations are clearly detailed in Anderson et al. (1992). This study remains the only national-scale quantitative detailed source of information for Maldives reef fisheries to date. Maldives was also included as part of a reef fishery global meta-analysis (Newton et al., 2007), but the source of information (FAO FISHSTAT database including mostly tuna statistics for Maldives), the lack of consideration given to geographical (intra-nation, inter-atoll, inter-habitat) differences, and general selected thresholds for sustainability did not allow to draw at the national level a relevant picture of Maldives reef fishery. Maldives was nevertheless categorized with an overall low risk of overexploitation by Newton et al. (2007), which is in agreement with the final conclusions drawn by Anderson et al. (1992), who used different criteria and highlighted some caveats depending on targeted species, atolls and habitats.

In addition to the lack of recent reliable fishery data to report on resource status, a number of known factors, listed below, but of unknown consequences, called for new assessments to be conducted:

- Resort construction and increase of tourist accommodation is encouraged at the national level. The tourism industry of Maldives attracted close to 1 million tourists in 2010 (Ministry of Tourism, Arts and Culture, 2011). Similar projections and higher have been made for the future.

- A greater number of Maldivians as well as the 70,000+ expatriates working in the Maldives (Ministry of Higher Education, Employment and Social Security, website accessed April 2008) are growing to appreciate the value of reef fish to complement the usual tuna diet.
- In 2005, a study on the Maldives grouper fishery showed declines in catches and increases in smaller sized individuals (Sattar and Adam, 2005) suggesting that a fresh assessment of the entire Maldivian reef fishery was needed.
- Field observations suggest that exploitation of reef fish was carried out by fisherman in a similar manner to that of tuna (in terms of fishing without any limits), the latter of which has proven to be sustainable for decades even under long-term intense exploitation. However tuna and reef fish have comparably different life traits, fecundities and reproductive biology, growth rates, and population renewal time.
- Development of the fishery for large yellowfin tuna, which is seasonal, has led to exporters turning to reef fish during low season for tuna.
- The reef fishery provides an easier source of income in comparison to tuna fishing where fishermen have to travel long distances and spend hours, at times days away from their home and families. Reef fishing usually requires less effort (number of hours) and can be carried out close to the islands.
- Although reef fishing was carried out on a small-scale, it still played an important role in the livelihoods of island communities; many people fish reefs on an opportunistic basis whereas others carry out reef fishing as part-time employment.
- Many species of reef fish form spawning aggregations and it is evident that fishermen specifically target these aggregations, potentially removing a large part of the breeding population and at sustained exploitation levels may threaten the species (Tamelander et al. 2008).
- Finally, the effect of climate change on reef resources is unknown in Maldives. The country has previously suffered from significant coral bleaching, especially in 1998, with subsequent devastating damage to coral communities. This may have both, induced loss of habitat in the shallow reefs, and potentially impacted fish communities (Edwards et al., 2001, McClanahan et al. 2000; Loch et al. 2002; Loch et al. 2004; Bellwood et al. 2006).

Given all the aforementioned considerations, and to enable future informed and sustainable management of reef resources, it was necessary to draw an updated image of the fishery, including: its extent, the catch (quantity and composition), the gear and methodology used as well as the fate of the catch (i.e. whether it is sold to resorts or exported). We intend here to provide this much needed updated view (focussing on finfish only) using three data sets collected from:
1) Survey trips with fishermen of Central Maldives atolls to obtain fishery-dependent data on catch composition, fishing gears and methodology;
2) Collection of reef fish purchase data from tourist resorts in Maldives; and
3) Analysis of reef fish export trends based on export data collected by Maldives Customs Services.

MATERIAL AND METHODS

Reef Fishery Catch Data

Data on fishing locations and methods, main catch species and size compositions of species (Table 1, in appendix at the end of the text) were obtained in 2006 and 2007 by participating in fishing trips (n=102) with reef fishermen. Efforts were made to join the fishing trips throughout the year, irrespective of season. Species-level identification was systematic in 2007, but in 2006 catch composition of the Carangidae and Lethrinidae families could not be detailed.

As the tourism industry plays a central role in the reef fishing industry, targeted atolls were chosen based on the number of currently functional tourist resorts present in the atoll with the highest numbers of resorts falling in the Central part of the Maldives. From these atolls (namely Alifu Alifu, Alifu Dhaalu, Baa, Kaafu and Vaavu Atolls), specific islands (n=7) were chosen based on phone surveys to the Atoll Offices which identified islands where reef fishing was a regular activity and a primary source of income.

Length-frequency data for different reef fish species caught during both targeted reef fishery and as bycatch in other fisheries was also obtained from the Malé fish market during repeated visits (n=15) in 2007. Catch sold at the Malé fish market are mostly from North and South Malé Atoll.

To estimate the 2006-2007 total catch of reef fish on an annual basis and on an atoll basis, the catch data from the three atolls with the most extensive data (Alifu, Baa and Vaavu) was extrapolated by considering the surface area of lagoons and reefs for each atoll (respectively 2267, 1194 and 1058 km^2, Andréfouët et al., 2009) and fishing capacities observed during the fishing trips. Table 2 shows the number of fishing vessels in these 3 atolls as reported by the atoll offices and an estimation of the total number of fishing trips made by these vessels per month considering 21 days per month (i.e. after accounting for Fridays, public holidays and days with bad weather).

Table 2: Number of fishing vessels per atoll and island, and estimates of number of trips made by these vessels on a monthly basis.

Atoll: Baa	No. of vessels	**Atoll: Alifu Alifu / Alifu Dhaalu**	No. of vessels	**Atoll: Vaavu**	No. of vessels
Kudarikilu	4	Rasdhoo	2	Fulidhoo	2
Dharavandhoo	1	Ukulhas	4	Felidhoo	4
Dhonfanu	3	Bodufulhudhoo	9	Keyodhoo	4
Kihaadhoo	2	Mahibadhoo	3		
Thulhaadhoo	3	Mandhoo	1		
Eydhafushi	4	Kunburudhoo	3		
		Dhigurah	2		
		Dhihdhoo	1		
Total	17		25		10
Estimated no. of fishing trips/month	357		525		210

The average weight of catch per fishing trip per atoll was then used to infer the total annual catch from each atoll, for Baa, Alifu Dhaalu and Vaavu Atolls.

Reef Fish Purchase and Consumption by Tourist Resorts

The main consumers of reef fish are tourists. To estimate the total catch and consumption rates normalized by occupancy rates and total number of beds on an annual basis, tourist resorts were surveyed in 2006 and 2007 via a questionnaire which was sent to all resorts through the tourism ministry. Approximately 20% of operational resorts responded to the questionnaire and provided their reef fish purchase records, while only one resort provided details of their occupancy rates. We initially requested reef fish purchase quantities and prices on a species level and on a daily basis. However, most resorts pay a set price per kilo of reef fish regardless of the species composition. As a result, available records only show aggregate reef fish purchase. Data obtained from this survey were used to estimate average prices and revenues for fishers as well as normalized consumption rates. Results from this survey were generalized to all resorts.

Reef Fish Exports

Fisheries Statistics annually publish export values and prices of reef fish by both government and private sectors. Reef fish are exported fresh/chilled, dried or salt dried. Additionally grouper exports are reported here separately both as fresh/chilled and live.

Atoll Mapping Data

Fishing locations were overlain on atoll maps provided by the Millennium Coral Reef Mapping Project (MCRMP) to characterize the preferential areas targeted by fishermen during fishing trips (Andréfouët et al., 2006, 2009). Using high resolution satellite imagery, the MCRMP provided detailed geomorphological maps as well as consistent and accurate statistics of reef area for each Maldivian atoll (Andréfouët et al., 2009).

RESULTS

Fishing Trips Patterns and Fishing Gear

A total of 102 fishing trips were made within a period of two years (2006-2007). Islands visited and the numbers of fishing trips made from each island are listed in Table 3. The exact location of fishing sites were recorded with a GPS (Fig. 1) in order to help identify the commonly targeted sites, which could be potential spawning or feeding aggregation sites. Identification of such sites makes it easier to flag them for further management actions. In most cases fishermen did not venture away from their atolls. If they did, they remained close enough to their atolls to be able to return to their islands daily.

Table 3: Atolls and islands visited with number of fishing trips in 2006 and 2007. Kaafu Atoll comprises North and South Malé atolls.

Atoll	Island	Number of trips	
		2006	2007
Alifu Alifu	Rasdhoo	8	
Alifu Dhaalu	Mahibadhoo	11	17
Baa	Kudarikilu	13	11
Kaafu	Male'	6	3
Vaavu	Felidhoo	8	12
Vaavu	Fulidhoo	5	7
Dhaalu	Meedhoo		1
	Total	**51**	**51**

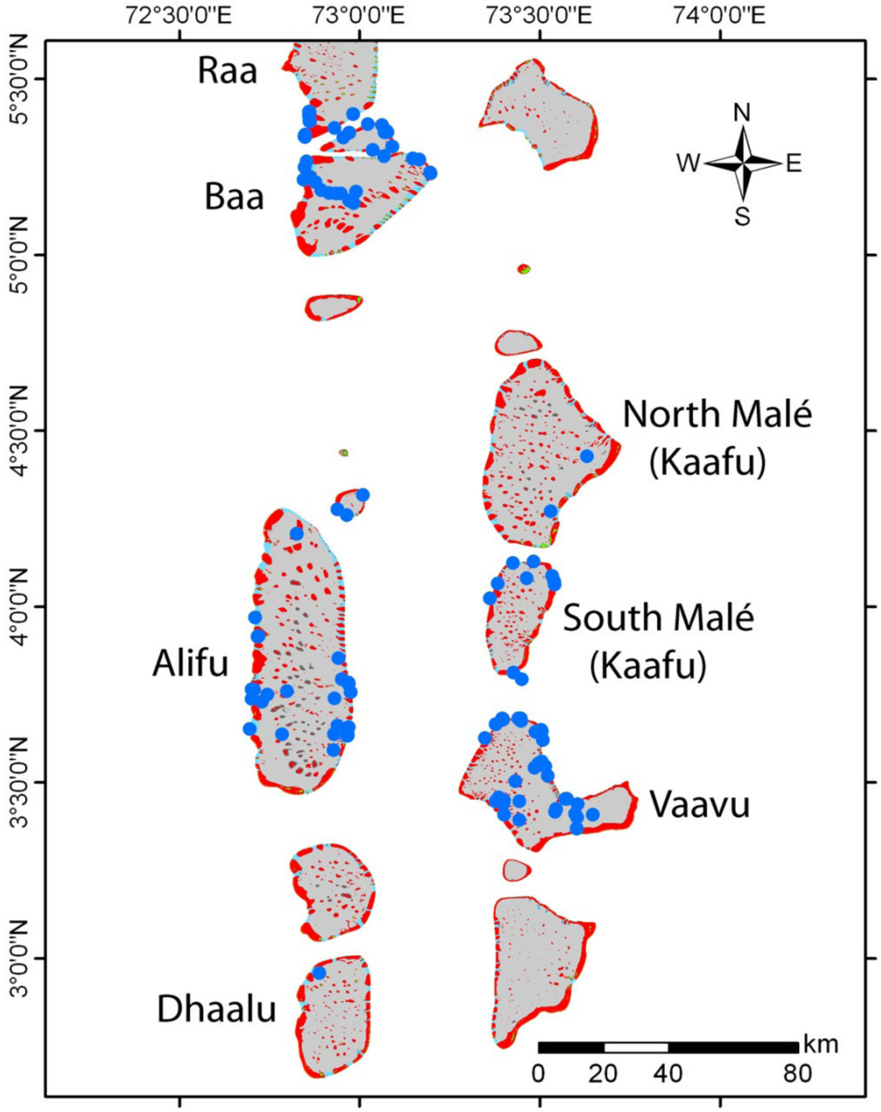


Figure 1. Map of Central Maldives and areas where fishing was carried out during the fishing trips participated in 2006-2007 (blue dots).

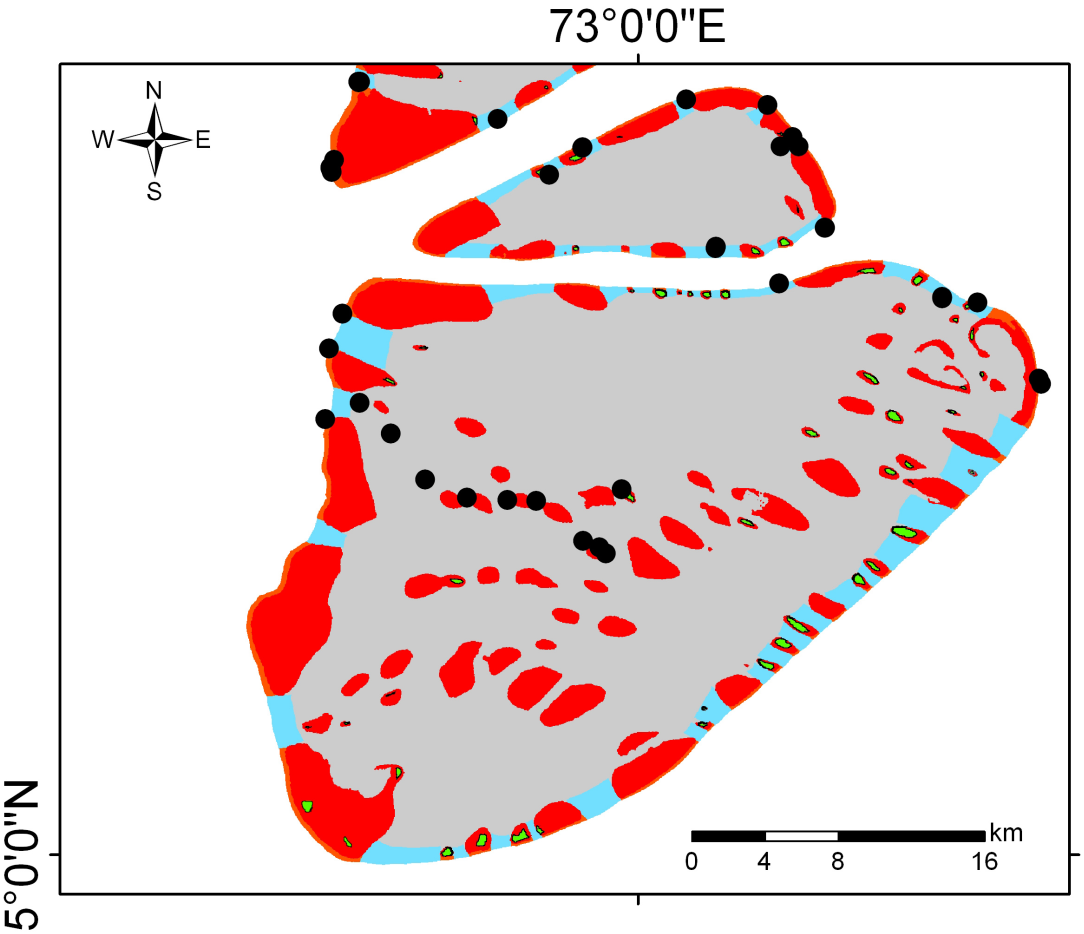


Figure 2: Location of fishing sites on Baa Atoll. Fishing sites (black dots) are located on the edges of passes (blue), oceanic deep slopes and lagoonal patch reefs (red), and at the limits of productive habitats such as coral reef flats and forereefs. Land is indicated by green colour.

Fishing locations were in most cases on forereefs on the oceanic side of atolls, in passes and at the edge of lagoonal patch reefs (Fig. 2). Small isolated submerged reefs (locally named *thila* and *haa*) were also frequently targeted (Fig. 2). With few exceptions, fishermen tended to avoid deep lagoon and deeper offshore areas.

Fishing was carried out on standard mechanized fishing boats (called *mas dhonis*) with an average of 5 crew per trip. On average, trips would last up to 12 hours, starting most commonly around 6 am. The crew would first collect bait (30 minutes up to 3 hours) then proceed to the fishing grounds (from 3 hours up to 9 hours fishing). On occasion, they would visit two to three fishing locations in one trip and return on a regular basis to particular sites. After fishing, fishermen would sell their catch to resorts or to small-scale fish processors who cook and salt/dry the fish

Fishing was carried out using a variety of gears, depending on the species being targeted: hand-lines, drop-lines, trolling and pole and line (Fig. 3).

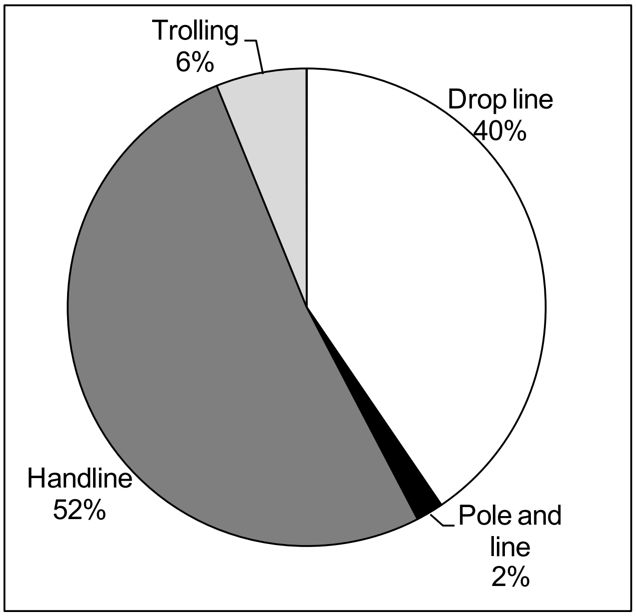


Figure 3: Proportions of gear types used by fishermen during the 2006-2007 surveys

Pole and line gear is used specifically to target tuna and is not discussed further.

- *Hand-lining:* Hand-lining was the most common method observed on all trips. Hand-lines were baited with live bait (mainly various species of fusiliers and damselfish). Since these lines do not have any weights on them they do not sink to the bottom and are used to target fish schools in the upper layers of the ocean such as trevallies.
- *Drop-lines:* Drop-lines were similar to hand-lines, but included a weight to sink them to the bottom. These lines are also baited with live bait. Another situation where drop-lines were used was when fish could be spotted by snorkelling (visually aided handlines).
- *Trolling:* On most trips, trolling was commonly employed while travelling between fishing grounds to catch large pelagic species, but not reef fish species. Targeted species included kawakawa (*Euthynnus affinis*,), wahoo (*Acanthocybium solandi*) and sailfish species (*Istiophorus platypterus*).

These preferential fishing gears were suitable for the observed fishing locations, namely at the edge of shallow reefs (Fig. 2). Multi-hook long-lines used by Anderson et al. (1992) for deep lagoon and oceanic slopes during their experimental campaigns were not used by fishermen. This implies that rigorous comparisons between the present study and Anderson et al., (1992) should be limited to the 1990-1991 hand-line data collected during the day because they targeted the same habitats. It is worth pointing out here that most destructive reef fishing gears used elsewhere in the world, such as spear guns (Cinner et al., 2009), are banned in Maldives.

In this study, fishing trips made from Felidhoo (in Vaavu Atoll) targeted groupers only. The main difference between these targeted grouper fishery trips and those targeting general reef fish was gear used, namely visually-aided handlines. For this, the fishermen enter the water with a basket used to hold the catch. Once a grouper is spotted, a baited line (live bait) is dropped in the vicinity of the grouper. This is a very popular way of fishing (Sattar and Adam, 2005). In Vaavu atoll, catch is sold to the grouper cage (holding facility used by exporters) located within the atoll, near Keyodhoo. In Faafu Atoll, fishermen head out for a week or a month at most, and sell their catch at the end of the trip to cages in other areas, mainly Malé atoll. Grouper fishing trips always end before sunset, in contrast to all other reef fishing trips for which best fishing occurs at dusk, just after sunset.

Incomes

All reef fish fishermen sold their catch to tourist resorts within their atoll or nearby atolls, or in Malé fish markets for fishermen close enough to Malé. Selling to resorts fell into three categories:

- Vessels that are contracted by resorts and sell their catch solely to that resort. Under these contracts, vessels have to provide a certain quantity of reef fish on a monthly basis;
- Vessels that visit 3 to 4 resorts at a time, depending on demand or requests from the resort. If no requests are made, then the fishermen will visit one of the resorts at random;
- Resorts have their own staff who carry out fishing to meet the resorts requirements. These fishermen are on the payroll of the resort.

Fishermen earned an average income of approximately 1800 Maldivian Ruffiya (MRf) (or 140 US$ as in January 2011) per fishing trip. Purchase rates were on average MRf 10 (i.e. less than 1 US$) per kilo of fish in resorts, and as low as MRf 5 per kilo at small-scale processors like in Kendhoo. Some resorts in Malé Atoll paid higher rates for *Acanthocybium solandri* and *Istiophorus platypterus*. Species such as *Euthynnus affinis*, if brought to the resort in large quantities were bought at lower prices than that being paid for reef fish. Fishermen earned more by selling at the market than at resorts, as the prices there varied depending on the species and the size of the individual.

Grouper fishermen sold their catch to the nearest grouper cage or to the exporter who offered the best price. Purchase records from the grouper cage showed that they classed groupers into different price categories depending on species and weight of individuals. On average each grouper fishing trip yielded an average income of MRf 1000 (~75 US$) per trip (for an average catch of 35 groupers per trip). However, it should be noted here that the grouper trips made by the fishermen of Vaavu atoll are very different from the trips made by the fishermen of Faafu atoll, who are the leaders of this fishery. These fishermen also earn a higher income per trip than Vaavu atoll fishermen.

Catch Data

Over two years, fishing trips showed the following total composition (Fig. 4): *Carangids* (41.63%), *Lutjanids* (21.56%)*, Scombrids* (13.66%)*, Fistularids* and *Sphyraenids* (9.11%)*, Lethrinids* (6.79%), *Serranids* (5.85%)*, Coryphaenids* (0.25%) and *Xiphiids* (0.22%). Fistularids and sphyraenids were grouped together because data collection was based on local names, and both families are known as *tholhi* in Dhivehi. However, statistics of both families could be separated afterwards by looking at the length frequency plot of the collective group.

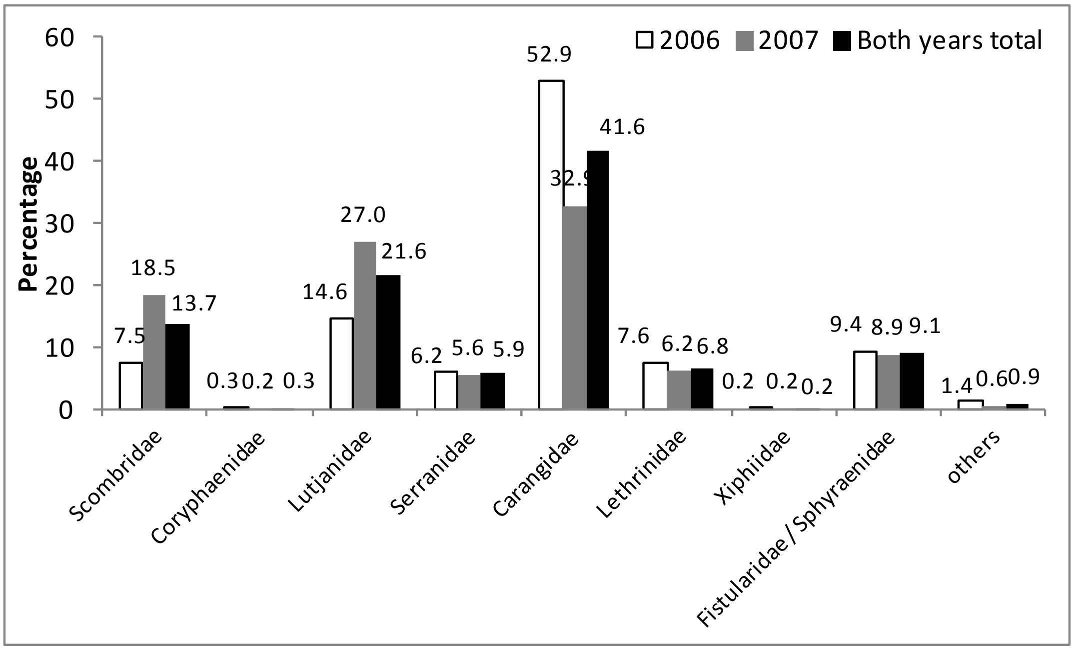


Figure 4. Percentage catch composition by numbers, of fish families caught during 2006-2007 fishing trips

In terms of number of individuals, the contribution of carangids towards the catch in 2006 and 2007 was high, but with significant annual variation. Carangids contributed more than 50% towards the catch composition in 2006, whereas in 2007 they contributed only approximately 30% towards the total. Among the carangids, the rainbow runner *Elagatis bipinnulata* contributed approximately 40% towards total catch in 2006. However, in 2007 the contribution of *E. bipinnulata* was considerably lower (approximately 15%) and the catch that year was dominated by jacks and *Aprion virescens* (with 18% and 15% respectively). Apart from Carangids, Scombrids and Lutjanids were also seen to contribute more towards the total catch in 2007 in comparison to 2006.

An island-based breakdown of total catch quantities in number of individuals over the 2 year survey period is shown in Figure 5 for Malé, Mahibadhoo, Fulidhoo, Felidhoo and Kudarikilu. Carangids form the larger group in the catch of all islands except for Felidhoo where catch is dominated by serranids due to the established grouper fishery. In 2006, all operational vessels in the island targeted grouper.

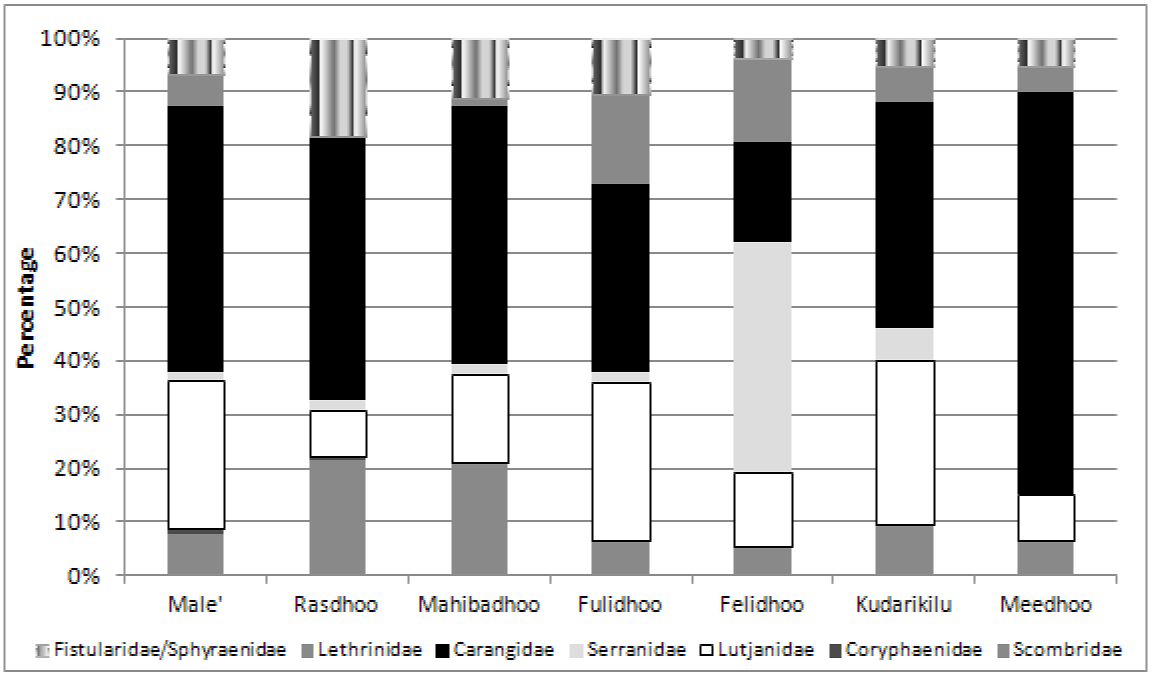


Figure 5. Island-based breakdown of catch numbers by main fish families.

Figure 6 shows the average weight and length for five of the main species for which length were recorded during fishing trips; *Lutjanus gibbus*, *Elagatis bipinnulata*, *Euthynnus affinis*, *Aprion virescens* and *Lutjanus bohar*. Length frequency distributions for these species are shown in Sattar (2008). Figure 7 provides here length frequency distributions for the main family groups.

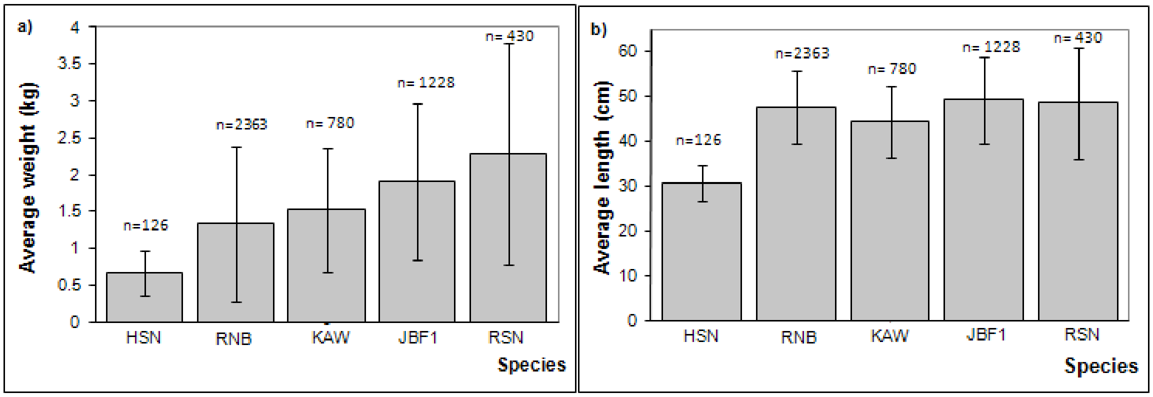


Figure 6. Average weight (a) and length (b) of the five main species caught during the surveys (HSN – Humpback snapper, RNB – Rainbow runner, KAW – Kawakawa, JBF1 – Green Jobfish, RSN – Red snapper). Error bars are standard deviations. See Table 1 in Appendix for scientific and Dhivehi names for each code

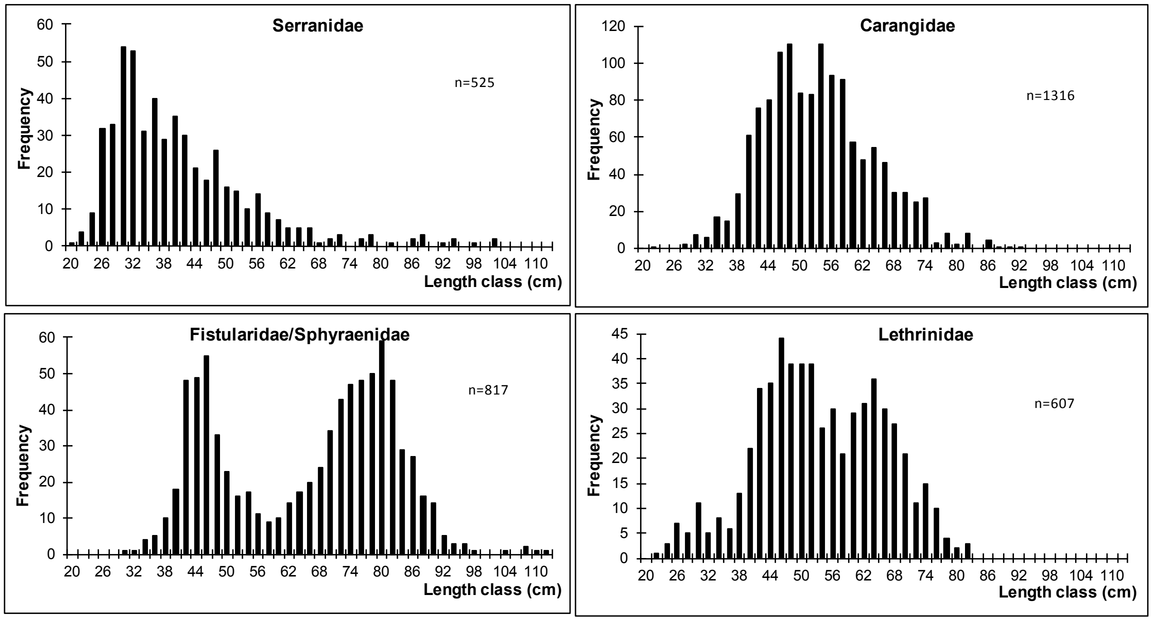


Figure 7. Size compositions of families and species assemblages caught during the 2006-2007 surveys.

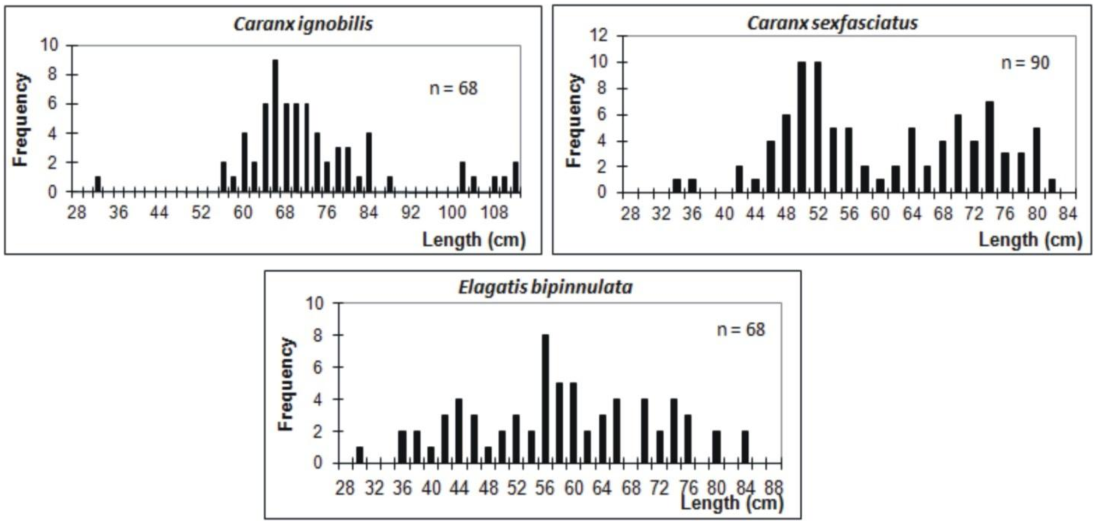
Carangids and Lethrinids display peaks at lengths between 40 and 60 cm, whereas Serranids show peak lengths in the smaller size classes, i.e. between 25 and 40 cm. 88% of the groupers were identified at a species/genus level, with 65% of these individuals belonging to the *Epinephelus*, *Plectropomus* and *Variola* genera.

Fishermen made an average of 525, 357 and 210 fishing trips per month for Alifu, Baa and Vaavu respectively. Using the average weight of catch per fishing trip for each atoll and the total area of each atoll, we inferred the total annual catch at 1452, 780, and 408 tonnes of fish for Alifu, Baa and Vaavu respectively, or in other words a yearly catch rate of 0.64, 0.65 and 0.38 tonnes per km^2 of reef-lagoon respectively.

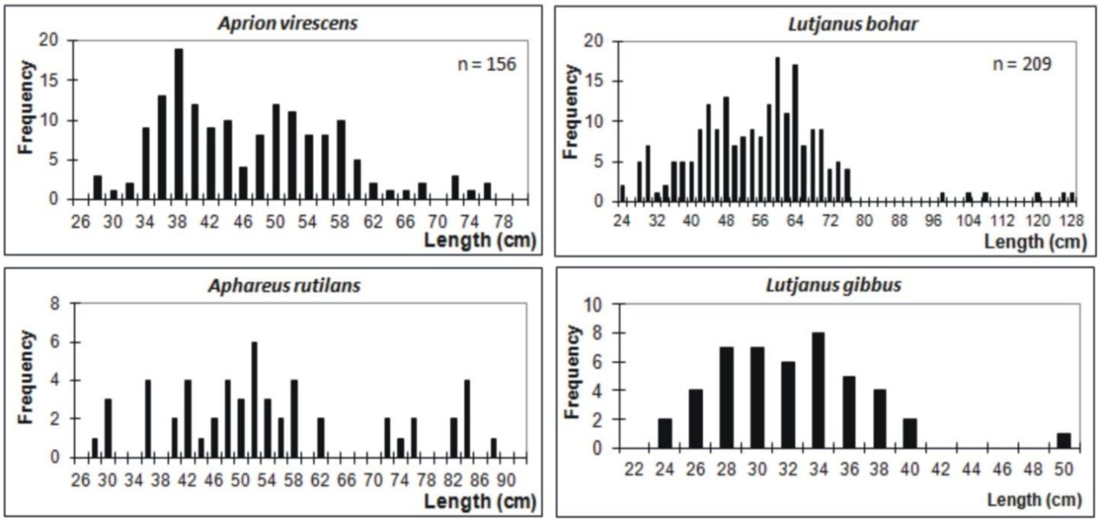
Malé Market Length Frequency Data

The most commonly represented families were Carangids, Lethrinids, Lutjanids, Coryphaenids, Sphyraenids and Serranids. Lengths were recorded for each species. Figure 8 reports length frequency for the most common species found at the market in 2007.

Family: Carangidae

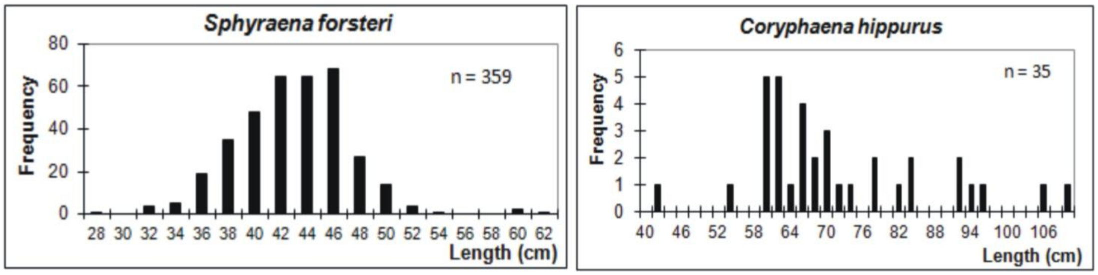


Family: Lutjanidae



Family: Sphyraenidae

Family: Coryphaenidae



Family: Lethrinidae

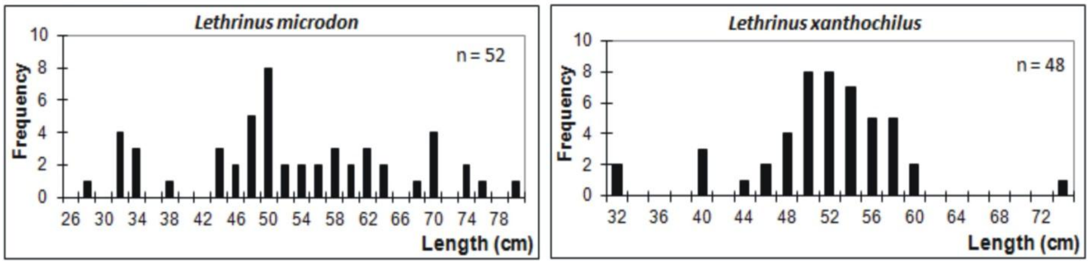


Figure 8: Length frequencies of the most commonly observed species in the Malé market, presented by families

Reef Fish Purchase and Consumption by Tourist Resorts

Only approximately 20% of the 90 Maldivian resorts contacted replied to our survey questionnaire on reef fish purchase records, while resort occupancy rates were received from only one resort. Extrapolation based on one resort's reef fish purchase for the whole year of 2006, its occupancy rate for 2006 and its number of beds, indicates that for each tourist night, an average of 1.29 kg of fish (whole fish, not cleaned or filleted) was purchased by the resort. The total number of registered beds in all resorts and hotels in Maldives for the year 2006 was 18,407 (MoTCA, 2007) and the average occupancy rate was 81.8% (MoTCA, 2007). Therefore for a total 5,495,778 tourist nights, the quantity of reef fish purchased by all resorts in 2006 would have been approximately 7100 metric tonnes. This is more than 3 times the amount (i.e. 2064 tonnes) purchased by all resorts in 1988 (Anderson et al., 1992).

Export of Reef Fish

Reef fish exports were dominated by the private sector, especially in the case of live exports, primarily of groupers to vessels visiting the holding cages. Official statistics showed that the private sector exported 99% of the volume of all reef fish exports. Trends in the export quantities for the last 12 years showed that exports of processed fish (fresh/chilled and salt/dried forms) declined abruptly in 1998 and since have stabilised around this lower range (50% less than prior to 1998). The live trade dominated by the export of species such as *Epinephelus fuscoguttatus, Plectropomus areolatus, P. pessuliferus* and *P. laevis* has been registering a steady decline (with the exception of a peak in 2001) since 1995 who dominate these exports.

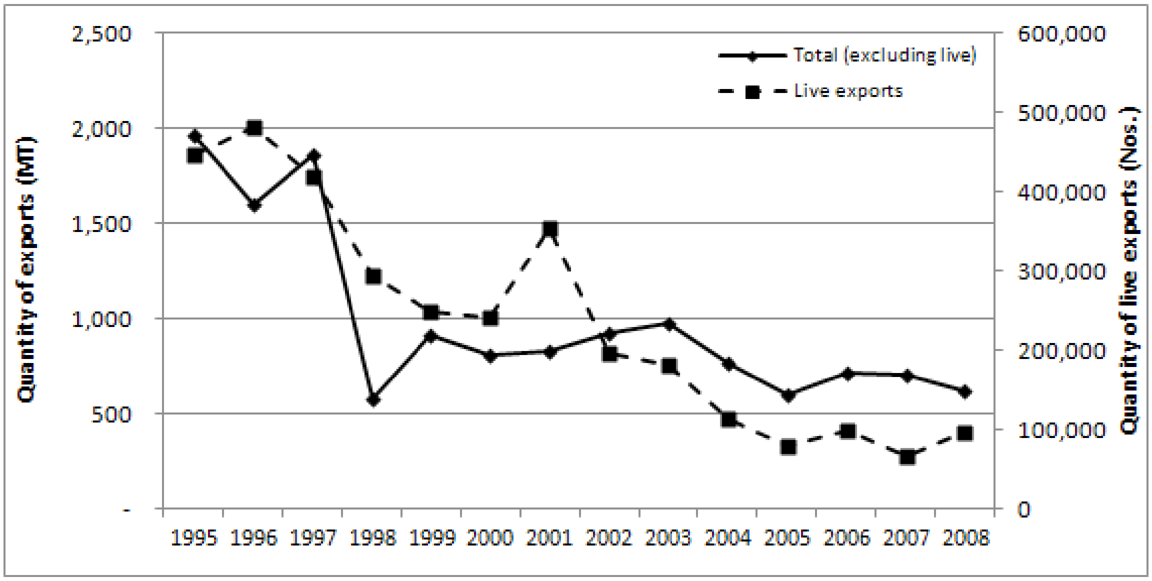


Figure 9. Total export quantity (MT) of processed fish (excluding live exports) (solid line) and Total export quantities of live reef fish in numbers (dotted line) for the last 14 years. Source: MoFAMR Basic Fisheries Statistics (1995-2008).

DISCUSSION

The 2006-2007 surveys provided a wealth of fresh data on the Maldivian reef fishery. The sampling targeted a variety of sources including fishermen during fishing trips, the current main consumers (resorts) and official export statistics. These different sources of information allowed us to draw an updated picture of reef fisheries, and to compare our findings with previous surveys from the early nineties (Van Der Knaap et al., 1991; Anderson et al*.,* 1992). However it is important to note that, the studied atolls were different (except for Alifu and Malé), and that only a fraction of the fishery catch data (from day hand-lining and drop-lining data) can be rigorously used for comparison. In the future we hope that the data presented here can also be used for comparison with other regions of the world where reef fisheries, access to fish protein by the local population and therefore food security are at risk (Bell et al. 2009). Further, we also hope to expand the number of resorts that will provide their statistics on occupancy rates and fish purchase. One weakness of the present study lies in the extrapolations based on only one single resort.

The yield from Vaavu atoll (0.38 tonnes per km^2) is half of that from Baa and Alifu Dhaalu atolls, (0.064 and 0.65 tonnes per km^2 respectively) highlighting that generalizing results from one atoll to the next need to be made cautiously, due to either naturally different stocks or different fishing pressure. Anderson et al. (1992) call for similar prudence in their multi-atoll study. Reef fishing pressure is lower in Vaavu atoll in comparison to Baa and Alifu atoll due to the smaller market (i.e. two resorts at time of survey) in comparison to the available market in Baa and Alifu Dhaalu atoll (6 and 16 resorts respectively).

The 0.64, 0.65 and 0.38 yield values are 1/5th to 1/15th lower than published average yield per km^2 of coral reefs, which generally range between 1 and 10 tons per km^2 worldwide (Dalzell et al., 1996; Newton et al., 2007; Bell et al., 2009). However, since reef fishing locations were quite specific and situated around reef edges and passes (Fig. 2), the catch rate per km^2 is *de facto* largely underestimated when including lagoon areas that were not fished here. Considering only the surface of productive fished reef flats, slopes and passes (428, 299 and 234 km^2 for Alifu, Baa and Vaavu respectively), the ratio amounts to a more typical, 3.39, 2.6 and 1.74 tonnes per km^2 for Alifu Dhaalu, Baa and Vaavu respectively. This suggests that the rate of fishing based on data collected 2006/2007 is close to the limit of sustainability, if we used the published guidelines from other coral reef areas. However, wide lagoon areas remain fairly untouched.

Long-line fishing by Anderson et al. (1992) in lagoon areas provided substantial catches for a number of species that were targeted by the fishermen during our reef survey trips (cf. table 8 in Anderson et al., 1992), including the green jobfish *Aprion virescens* and red snapper *Lutjanus bohar*. It is thus surprising that these areas were not often targeted, though they would require different fishing gear. The fact that fishermen seem to stick to an easy-to-deploy fishing gear and to shallow areas suggest that they have not yet found obvious signs of resource depletion in their usual fishing grounds, nor the necessity to change their habits. Another interpretation would be that these areas have been depleted of fish of commercial value during the period between the two studies.

However, this is unlikely given the size of the lagoons, current fishing pressure levels, life traits of several of these species (e.g. jacks are highly mobile fishes) and the yields and estimated total biomass reported by Anderson et al. (1992).

Besides changes in catch per unit effort that remain difficult to quantify here and compare between studies, other indicators of possible overexploitation would be changes in catches (size and species) between the last ~20 years, as well as the current sizes of the catches compared to overfished areas worldwide. In 1989-1991, the most frequent species caught by hand-lining was *A. virescens*. This happened in every studied atoll (Shaviyani, Alifu and Laamu) and *A. virescens* contributed 32% of the total catch, on average, in weight. It was followed by *Epinephelus polyphekadion* (6.4%), *Lethrinus microdon* (5.3%) and *Lutjanus bohar* (5%). In comparison, in the present survey, *A. virescens* contributed only 13.9% towards the total catch over the 2 year period and the dominant catch was the rainbow runner *Elagatis bipinnulata*. Comparison of average weight of current catch with data obtained in the reef resources survey carried out in 1989/1991 (see Appendices I-IV in Anderson et al. 1992) suggest a decrease in average weight for *A. virescens*, *L. bohar* and *E. affinis* (Fig. 10).

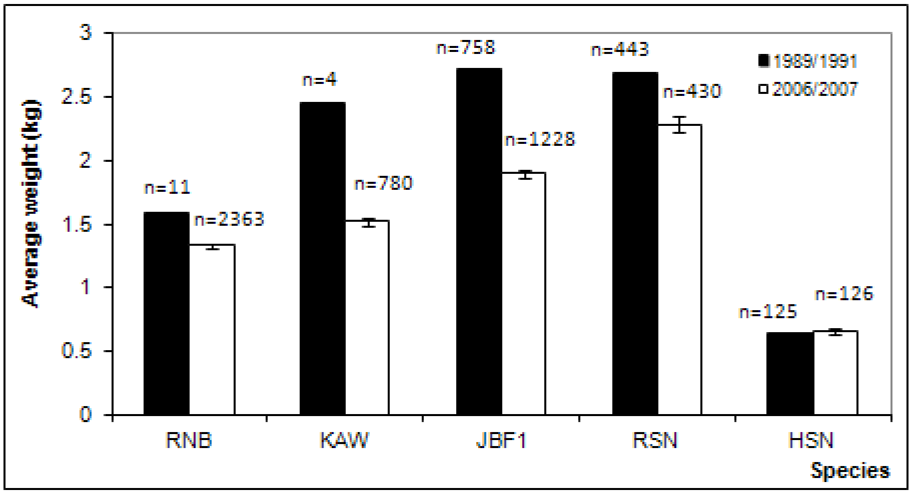


Figure 10. Comparison of average weight of main species caught in the current fishery with observations made during the 1989/1991 survey (HSN – Humpback snapper, RNB – Rainbow runner, KAW – Kawakawa, JBF1 – Green Jobfish, RSN – Red snapper). Error bars are standard error. See Table 1 in Appendix for scientific and Dhivehi names for each code. The 1989/1991 data are estimated using all fishing gear types.

Comparing our average caught fish sizes with those recorded in other areas worldwide is difficult. First, reef fishery-dependant data collected during fishing trips or in markets are scarce, not frequently updated and when they are provided in accessible literature, they may consider species that are not of interest, or absent, in Maldives fisheries. Anderson et al. (1992) noted that in Apo Island, in Philippines, only one third of the species and catches caught would be of interest for Maldivian commercial and subsistence fishery (Alcala and Luchavez, 1981). Rabbit fishes (Siganids) commonly caught and consumed in Asia and in the Pacific are completely ignored by Maldivian fishers and consumers (pers. obs., and Philippe Borsa pers. comm.). Conversely, *Lutjanus* *bohar*, a prominent Maldivian catch is very often a ciguateric poisonous fish in the Pacific Ocean where it does not contribute to fishery statistics. Fishery-independent length and weight data collected by underwater visual census (UVC) are more easily accessible (e.g. Graham et al., 2005), but UVC data does not necessarily reflect fishery pressure, except when the contrast in fishing pressure is very high (Pet-Soede et al., 2001), which is unlikely to be the case presently in Maldives.

In theory, North Malé Atoll could be an interesting point for temporal and spatial comparison because i) it is historically the first atoll where significant tourism development occurred, ii) it is the most heavily populated atoll with the presence of the capital, and iii) its fish market attracts a large number of sellers (mostly from North and South Malé atolls) and buyers. Thus, it can be assumed that any signs of overexploitation would first be apparent in the Malé fish market data. However it is important to note that Malé fish market is predominantly a tuna market, and reef fish are landed opportunistically there as by-catch, and not regularly. Analysis of the data summarized in figures 6 and 8 show that *E. bipinnulata* individuals at the Malé market were generally larger (modal length at 56 cm) than those observed on the fishing trips (modal length at 46 cm). Conversely, *A. virescens*, peak length was shorter (38cm) at the Malé market. For most other species, size classes distribution commonly observed in remote atolls and those at Malé market were similar, including for *L. bohar* and *L. gibbus*. In the case of *L. bohar,* very large individuals (i.e. 100+ cm) were also reported at the Malé market. Even if these large specimens could reveal fishing during spawning seasons in shallow areas (older specimens live deeper, Anderson et al. (1992)), we conclude that there are no signs of overfishing from Malé fish market data when compared to other atolls. Moreover, similar conclusions arise when comparing with historical Malé data from Van Der Knaap et al. (1991) and Anderson et al. (1992). Anderson et al. (1992) had already noted the surprisingly good shape of the resources in Malé atoll compared to other sites, given its high fishing pressure.

However, it should be noted here that, while the species caught in the generic reef fishery which targets the tourism market, seem to be in good condition with respect to their stocks, the grouper stocks show a completely different picture. Groupers have been intensively exploited since the early 1990s, for the export market and the fishery and export industry have been showing quite a worrying trend. Grouper fishery is on a decline with decreased catch quantities comprised of high number of small sized individuals. This is especially true for the high valued species such as those belonging to Epinephelus and Plectropomus genera. More than half of serranids sampled during the fishing trips belonged to genera/species that are capable of growing to larger sizes, such as *Epinephelus*, *Plectropomus* and *Variola*. Hence the peak lengths at small size classes for groupers reveal a worrying trend, i.e. the catch of small individuals of species which could grow to much larger sizes.

Fish market data cannot be related with export data, but these also contribute significantly to the reef fishery industry. Figure 9 shows the amount of fish exported to foreign markets. Since 1996, there is a general decrease in weight for both processed (salted, dried, or fresh/chilled fish) and live fish trades. It must be noted that rainbow runners and wahoo make a significant part of the salted-dried processed exports, but not of the chilled-fresh exports (separate data not shown). The decrease for the years 2004 and 2005 could be explained by the large number of fishermen leaving the grouper and reef fishery and turning towards yellowfin fishery at that time, possibly due to the better income from the fishery. In agreement with previous reports on live grouper exports (Sattar and Adam, 2005), the trend in total export quantities of live reef fish (groupers inclusive) is decreasing, due to the decreased availability of species and sizes required for the live market. Under-reporting is also likely and the official statistics used here may underestimate the actual level of exports. However, although export quantities of live reef fish are decreasing, buyers are paying higher prices for less available items. This in itself is an incentive for exporters and fishermen to maintain the activity in times of declining fisheries worldwide. The decline is also due to the apparent high turnover of owners of the cages used to maintain fish alive as observed between 2006 and 2007 during our surveys in Vaavu atoll.

Overall, Maldives reef fisheries seem currently at a state that does not show overexploitation of the resources, except for groupers. However, a number of caveats are worth taking into account. First, our estimated catch is likely an underestimate of the total as it does not account for the catch made by fishermen who fish on an opportunistic basis and sell their catch to the islands and villagers. It also does not account for the grouper fishermen from Baa atoll who do not get their catch solely from within the atoll, but make fishing trips throughout the Maldives, which could last for a month at the least (Sattar and Adam, 2005). Second, the reef fish market is not negligible compared to tuna and given current resort development plans is likely to continue increasing and expanding. Although lower than the value estimated by Van Der Knaap et al. (1991) (1.67 kg), the consumption rate is of the same order and suggest that future tourism development and higher number of tourists will steadily impact the reef fishery. Purchase prices of reef fish by the resorts varied between 5 to 18 MRf per kilo of reef fish, in agreement with the average purchase price observed on the fishing trips, i.e. MRf 10 per kilo of fish. This indicates that for the year 2006, an approximate total of MRf 71 million (US$5.5 million) was spent on the purchase of reef fish. Prices paid for reef fish purchases by resorts did not vary with the time of the year in comparison to what is observed in grouper cages where when fishing is low, exporters pay higher amounts than they would during periods of good fishing (Sattar and Adam, 2005). Third, the reef fish export industry is likely more wide-spread than the picture drawn through official statistics compiled for this study. Indeed, it is a common practice among yellowfin tuna exporters to turn towards reef fish during times of low yellowfin catches.

CONCLUSION

The data collected during the 2006-2007 surveys in Central Maldives atolls and Malé fish markets provided fresh insights and a new benchmark for the status of the fishery, compared to the previous assessments achieved 20 years ago, despite some constraints in comparisons due to study design differences.

Considering historical and new data, the status of the Maldivian reef fishery (apart from the grouper fishery) appears to be in good state, with opportunity to expand in the future, in contrast with many other island and atoll nations worldwide (Newton et al., 2007, Bell et al., 2009). On the good side, we report that dominant fishing gears were single hand-lines used in shallow areas around reef edges, and not the more destructive fishing devices used elsewhere such as spear guns or dynamite fishing (Pet-Soede et al., 2001, Cinner et al., 2009) which are banned in Maldives. The yield computed for the preferentially fished area is low to medium (1.7-3.5 tonnes/km^2), and well within the limits of sustainability considered elsewhere worldwide (Newton et al., 2007). Average caught fish sizes remain good, and exports of reef fish are decreasing. Furthermore, during these surveys, fishermen seldom fished the vast deeper lagoon areas that proved to be productive during the 1990-1991 fishing trips with long-lines (Anderson et al., 1992). Finally, data from the Malé fish market, despite being located on the most populated atoll, suggest that the population structures of the main targeted species have not been negatively affected and is similar to nearby Central Maldives atolls. On the other hand, it does not mean that the situation is exactly the same as 20 years ago, nor that signs of changes should not be taken seriously in view of increased demand from the local tourism industry and increased value of fresh and processed fish in export markets. Even if not considered here, other signs of degradation exist such as the rapid and severe decline of sharks due to the shark fin fishery (Anderson and Ahmed, 1993), before this practice was officially banned in 2009. For instance, Chabanet et al. (this issue) do not report any sightings of sharks in Baa atoll in their 2009 UVC observations.

Careful planning and management of fishery resources on an atoll basis will be needed shortly to account for other factors than current fishermen practices. For this, a robust long-term fishery monitoring and management program designed by atoll with varying environmental features and varying fishing pressure as well as varying management measures such as no-take zones and protected spawning aggregations would be needed in parallel to the monitoring of the quality of reef and lagoon habitats possibly damaged after bleaching events and other disturbances. Inter-atoll variations need to be taken into account if future monitoring occurs by considering the different rates of tourism development and the latitudinal environmental and geomorphological variations found across Maldives (Anderson et al., 1992). Monitoring of reef fish catch should be planned in coordination with the resorts. This can be enforced by making recording of their reef fish purchase (including details such as species and quantity purchased, date of purchased, fishermen details, and size and weight) an obligatory criterion for obtaining their license to operate. Proactive actions by the resorts themselves should be encouraged. For instance, one resort has its own regulations and did not purchase individuals smaller than a certain size or if they were immature, or did not purchase any fish at all if sharks were found on board even if caught accidentally. Species-specific regulations should also be further promoted at first signs of stock degradation since there are no management regulations for reef food fish except for the declaration of the Napoleon wrasse (*Cheilinus undulates*) as a protected species and the export ban on all species of parrotfish. This would complement current regulations and guidelines existing for the aquarium trade fishery and the bait fishery.

ACKNOWLEDGEMENTS

Several people have contributed to this project during its various stages. Most importantly we thank all the MRC staff who took part in the field trips and would like to note their hard work in collecting all data required for this survey: Mohamed Ahusan, Ibrahim Asghar, Haanee Badeeu, Hassan Haamid, Mariyam Shafiya Hassan, Fahmeeda Islam, Aminath Lubna, Shafiya Naeem, Ahmed Najeeb, Ali Yashau and Hussein Irufan. Secondly we would like to thank all the fishermen who took us out on their trips with them. Additionally, various tourist resorts contributed towards this study, both in their data contribution as well assistance on our visits to the resort with the fishermen. Thanks are also due to the staff of ERSS of the Ministry of Fisheries, Agriculture and Marine Resources, as well as all those at MRC and other government institutes and private companies who assisted during the various stages of this study. Last but not least we would like to thank all Atoll and Island offices, and island communities who assisted us on our various survey trips.

REFERENCES

Alcala, A. C., and Luchavez T.
1981. Fish yield of the coral reef surrounding Apo Island, Negros Oriental, Central Visayas, Philippines. *Proc. 4th Int.Coral Reef Symposium*, Manila. 1:69-73.

Anderson, R. C., Z. Waheed, M. Rasheed and A. Arif
1992. Reef Fish Resources Survey in the Maldives - Phase II Reef Fish Research and Resources Survey. B.o. B. Programme. Madras, Bay of Bengal Programme/ FAO: 54 p.

Anderson, R. C., and H. Ahmed
1993. The shark fisheries in the Maldives. Malé (MOFA), Rome (FAO), p. 1-73.

Anderson, R. C.
1997. The Maldivian tuna livebait fishery – Status and trends. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.

Andréfouët, S., F. E. Muller-Karger, J. A. Robinson, C. J. Kranenburg, D. Torres-Pulliza, S. A. Spraggins, and B. Murch.
2006. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. *Proc. 10th Int. Coral Reef Symposium.* Japanese Coral Reef Society, Okinawa, Japan. pp. 1732-1745

Andréfouët, S., N. Chagnaud, and C. Kranenburg.
2009. Atlas des récifs coralliens de l'Océan Indien Ouest. Atlas of Western Indian Ocean Coral Reefs. Centre IRD de Nouméa, Nouméa, Nouvelle-Calédonie. 102 p.

Ahmed, H., Mohamed, S., Saleem, M. R.
1997. Exploitation of reef resources – Beche-de-mer, Reef sharks, Giant clams, Lobsters and others. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.

Bell, J., M. Kronen, A. Vunisea, W. Nash, K. G, A. Demnke, S. Pontifex, and S. Andréfouët.
2009. Planning the use of fish for food security in the Pacific. *Marine Policy* 33:64-76

Bellwood, D. R., Hoey, A. S., Ackerman, J. L., Depczynski, M.
2006. Coral bleaching, reef fish community phase shifts and the resilience of coral reefs. *Global Change Biology* 12 **(9)**: 1587 - 1594

Cinner, J. E., T. R. McClanahan, N. A. J. Graham, M. S. Pratchett, S. K. Wilson, and J. B. Raina.
2009. Gear-based fisheries management as a potential adaptive response to climate change and coral mortality. *Journal of Applied Ecology* 46:724-732

Dalzell, P., T. J. H. Adams, and N. V. C. Polunin.
1996. Coastal fisheries in the Pacific islands. *Oceanography and Marine Biology*, 34:395-531

Department of National Planning
2010. Statistical Yearbook of Maldives 2010. DNP, Male', Republic of Maldives

Edwards, A. J., S. Clark, H. Zahir, A. Rajasuriya, A. Naseer and J. Rubens
2001.Coral bleaching and mortality on artificial and natural reefs in Maldives in 1998, Sea Surface Temperature anomalies and initial recovery. *Marine Pollution Bulletin* 42: 7-15

Graham, N., N. Dulvy, S. Jennings, and N. Polunin.
2005. Size-spectra as indicators of the effects of fishing on coral reef fish assemblages. *Coral Reefs* 24:118-124

Kulbicki, M.
1988. Correlation between catch data from bottom longlines and fish censuses in the SW lagoon of New-Caledonia. *Proc. 6th Int. Coral Reef Symposium*, Townsville. pp. 305-312

Loch, K., Loch, W., Shuchmacher, H. and See, W. R.
2002. Coral recruitment and regeneration on a Maldivian reef 21 months after the coral bleaching event of 1998. PSZN I: *Mar. Ecol*. 23 **(3)**: 219 – 236

Loch, K., Loch, W., Shuchmacher, H. and See, W. R.
2004. Coral recruitment and regeneration on a Maldivian reef four years after the coral bleaching event of 1998. Part 2. PSZN I **Mar. Ecol**. 25: 145 – 154

McClanahan, T. R.
2000. Bleaching damage and recovery potential of Maldivian coral reefs. *Mar. Poll. Bull*. 40: 587-597

Ministry of Higher Education, Employment and Social Security, website accessed April 2008:
http://www.employment.gov.mv/Resources/Statistics/2008/Indicators/Expatriate%20Employment%20Annual%20Growth%20Rate,%202003%20-%202007.pdf

Ministry of Tourism, Arts and Culture
2011. Tourism Yearbook 2011. Statistics and Research Section, Ministry of Tourism, Arts and Culture, Male', Maldives.

MoTCA.
2007. "Khabaru - midhiya aharu nimunu iru Raahje ah 601,923 fathuruverin ziyaaraiy kohfai vey." 88-SR/NEWS/2007/01 Retrieved January 29, 2007.

MRC

2009. "Miyaru masverikamuge haalathu 2". Marine Research Centre, Ministry of Fisheries and Agriculture. 33p.

Newton, K., I. M. Côté, G. M. Pilling, S. Jennings and N. K. Duly

2007.Current and future sustainability of Island Coral Reef Fisheries. *Current Biology* 17:655-658

Pet-Soede, C., W. L. T. van Densen, J. S. Pet, and M. A. M. Machiels.

2001. Impact of Indonesian coral reef fisheries on fish community structure and the resultant catch composition. *Fisheries Research* 51:35-51.

Saleem, M. R. and Adam, M. S.

2004. *Review of aquarium fishery of Maldives*. Marine Research Centre, Male', Maldives. 33p.

Sattar, S. A.

2008. *Reef fishery Survey 2006-2007*. Marine Research Centre, Malé. 66 p.

Sattar, S. A., and M. S. Adam

2005. *Review of grouper fishery of the Maldives with additional notes on the Faafu Atoll fishery*. Malé (Marine Research Centre), pp. 1-64

Shakeel, H. and H. Ahmed

1996. Exploitation of Reef Resources, grouper and other food fishes in the Maldives. Workshop on Integrated Reef Resources in the Maldives BOBP/REP/76: 312 p.

Tamelander, J., Sattar, S., Campbell, S., Hoon, V., Arthur, R., Patterson, E. J. K, Satapoomin, U., Chandi, M., Rajasuriya, A., and Samoilys, M.

2009. Reef fish spawning aggregations in the Bay of Bengal: awareness and Occurrence. *Proceedings of the 11th Coral Reef Symposium*, Ft. Lauderdale, Florida

Van Der Knaap, M., Z. Waheed, H. Shareef and M. Rasheed

1991. Reef fish resources survey in the Maldives. Reef fish Research and ResourcesSurvey. B. O. B. Programme. Madras, Bay of Bengal Programme/ FAO: 60 p.

Appendix

Table 1: List of studied fish families/species, in scientific, English and local (Dhivehi) appellations. Carangidae and lethrinidae were described at species level in 2007.

Code	**Scientific name**	**English name**	**Dhivehi name**
	Snapper (Lutjanidae)		
JBF1*	*Aprion virescens*	Green jobfish	Giulhu
JBF2*	*Aphareus rutilans*	Rusty jobfish	Rankarumas
HSN*	*Lutjanus gibbus*	Humpback red snapper	Ginimas
RSN*	*Lutjanus bohar*	Red snapper	Raiymas
FON	*Macolor niger*	Black and white snapper	Foniyamas
FON	*Macolor macularis*	Midnight snapper	Kalhu foniyamas
	Jack (Carangidae)		
RNB	*Elagatis bipinnulata*	Rainbow runner	Maaniyamas
JCK		Jacks (species level data absent in 2006)	Handhi
JCK	*Alectis ciliaris*	African pompano	Naruva handhi
JCK	Carangoides caeruleopinnatus	Coastal trevally	Vabboa handhi
JCK	*Carangoides ferdau*	Blue trevally	Dhabaru handhi
JCK	*Carangoides gymnostethus*	Bludger trevally	Mushimas handhi
JCK	*Carangoides orthogrammus*	Island trevally	Thumba handhi
JCK	*Caranx ignobilis*	Giant trevally	Muda handhi
JCK	*Caranx lugubris*	Black trevally	Kalha handhi
JCK	*Caranx melampygus*	Bluefin trevally	Fani handhi
JCK	*Caranx sexfasciatus*	Bigeye trevally	Haluvimas
JCK	*Gnathodon speciosus*	Golden trevally	Libaas handhi
JCK	*Scomberoides lysan*	Doublespotted queenfish	Kashi vaali
JCK	*Seriola rivoliana**	Almaco jack	Andhun handhi/ Andhun mas
SBR	**Emperor (Lethrinidae)**	Seabreams (species level data absent in 2006)	Filolhu
SBR	*Gymnocranius griseus*	Grey large-eye bream	Kandu uniya
SBR	*Lethrinus conchyliatus**	Redaxil emperor	Thun raiy filolhu
SBR	*Lethrinus harak*	Thumbprint emperor	Lah filolhu
SBR	*Lethrinus microdon**	Smalltooth emperor	Thundhigu filolhu
SBR	*Lethrinus olivaceus**	Longnose emperor	Filolhu
SBR	*Lethrinus rubrioperculatus**	Spotcheek emperor	Kalhihi
SBR	*Lethrinus xanthochilus**	Yellowlip emperor	Reendhoo thun filolhu

	Grouper (Serranidae)		
GRP	*Aethaloperca rogaa*	Redmouth grouper	Ginimas faana
GRP	*Anyperodon leucogrammicus*	Slender grouper	Boalhajehi faana
GRP	*Cephalopholis argus*	Peacock hind	Mas faana
GRP	*Epinephelus fuscoguttatus*	Marble grouper	Kas faana
GRP	*Plectropomus areolatus*	Squaretail grouper	Olhu faana
GRP	*Plectropomus pessuliferus*	Roving coral grouper	Dhon olhu faana
GRP	*Plectropomus laevis*	Black-saddled coral grouper	Kula olhu faana
GRP	*Variola louti*	Moontail seabass	Kanduhaa
	Tuna (Scombridae and Xiphiidae)		
KAW*	*Euthynnus affinis*	Kawakawa	Latti
WHO*	*Acanthocybium solandri*	Wahoo	Kurumas
DOG*	*Gymnosarda unicolor*	Dogtooth tuna	Voshimas
SL	*Istiophorus platypterus*	Indopacific sailfish	Fangandu hibaru
THL	Cornetfish (Fistularidae)	Cornetfish (species level data absent)	Tholhi
	Barracuda (Sphyraenidae)		
THL	*Sphyreana forsteri*	Bigeye barracuda	Faru tholhi
THL	*Sphyreana barracuda*	Great barracuda	Maa tholhi
	Others		
FIY*	*Coryphaena hippurus*	Dolphinfish	Fiyala
SQR	Holocentridae	Mainly sabre squirrelfish	Raiverimas

REEF FISH TAGGING PROGRAMME – BAA ATOLL PILOT PROJECT

BY

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ABSTRACT

Biology of reef fish species renders them easy to over exploit, with increasing fishing effort and unsustainable catch quantities. With the increasing demand for reef fish in the Maldives it is of essence that these populations be sustainably utilized to avoid overexploitation. However, proper management will only come through well-informed management decisions regarding their biology and behavior. The pilot reef fish tagging project was conducted in Baa Atoll, in collaboration with the Atoll Ecosystem Conservation Project. Conventional tagging using dart tags was carried out to study movement patterns of various reef fish species exploited in the multispecies fishery. Individuals of the most commonly exploited reef fish species were tagged and released on two survey trips from B. Kudarikilu. The pilot project had a recovery rate of 10.8% over a period of 1 year, which, while on the low side, is significant, in comparison to previous conventional tagging studies done in other parts of the world. Results from the study show that the most commonly exploited species, *A. virescens* (Green jobfish), travel relatively long distances, although on average they remain within the atoll or within a range of approximately 4 km. One of the main limitations of this project was the lack of awareness amongst all stakeholders involved. Nevertheless, despite some data limitations, it can be concluded that commercial reef fish species of the Maldives have a limited "home range" confirming previous knowledge on the targeted species. In terms of conservation and management recommendations, the results imply that in the Maldives, where human communities are separated by atolls and islands, due to geographic reasons, it would make sense to consider whole atolls as conservation units. We recommend similar tagging studies to be carried out on individual species of importance to study their biology and behavior. Further work should take advantage of the lessons learn from this pilot study.

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INTRODUCTION

Many reef fish are known to mature late, have long lives and low population turnover rates. It is also known that many species of reef fish aggregate to either feed or spawn. Many reef fish species are believed to be 'residents' i.e. generally stay near their place of first recruitment. Conversely, some species of groupers travel long distances to and from aggregations during spawning periods (Bolden, 2000). Aggregations sites which are well known and regularly targeted by experienced fishermen, have disappeared or shown a decrease in individuals per aggregation, due to intense fishing (Sadovy and Domeier, 2005). Clearly, biology and migration patterns of reef fish are critical information to ensure management plans can be developed to prevent overexploitation of these resources.

Various methods of tagging and mark recapture techniques, ranging from the conventional dart tags, to acoustic tagging, to chemical tags and Pop-up Satellite Archive Tags (PATS) are used throughout the world to study the behavior and biology of fauna both marine and terrestrial. Tagging studies which investigate population sizes, migration patterns, and growth rates are quite common for tuna populations of bigeye, yellowfin, skipjack and bluefin tuna, throughout the world. Same has previously been conducted in the Maldives with remarkable results (Yesaki and Waheed, 1992; Waheed and Anderson, 1994). However, relatively few studies have used tagging methods to study the behavior and ecology of reef fish species (but see Burns, 2009 for a grouper-snapper tagging study in Florida, the tagging study of *Amphiprion percula* and *Chaetodon vagabundus* by Almany et al. (2007) and the acoustic tagging of *Epinephelus maculatus, Plectropomus leopardus, Chlorurus microrhinos,* and *Scarus ghobban* by Chateau and Wantiez (2009) in New Caledonia.

A review of the reef fishery carried out by the Marine Research Centre showed that the reef fish consumption by resorts per tourist per night has decreased over the last 15 years. However, total reef fish purchase by resorts had increased three-fold, with an estimated quantity of 7000 metric tonnes of reef fish being purchased per year (Sattar 2008, Sattar et al., this issue). The review also estimated a total catch of 16,000 metric tonnes per year from the whole Maldives. Given the importance of this fishery to the Maldivian tourism industry and hence the economy, it is important to study fish behavior to gain as much insight as possible for sound management decisions.

Baa atoll is one of the most central atolls in the Maldives, both in terms of geography and economy. The atoll is well known for its world famous dive sites, beautiful coral reefs, marine biodiversity and the many tourist resorts scattered throughout the atoll, with more under construction. Given the spread of tourism within the atoll, reef resources are in high demand and the people of the atoll depend on reef fish as a direct source of income and to a lesser extent, as a source of food. Baa Atoll was chosen for this pilot tagging project, because of its central location and the importance placed by the community on reef resources as a source of their income.

Baa atoll has 13 inhabited islands, out of which 11 islands are reported to carry out reef fishing (including grouper fishery). At the time of the tagging project presented here, a total of 45 fishing vessels were active. The atoll has an estimated total surface area of 1240 km^2 (Naseer and Hatcher, 2004). An annual catch of 780 tonnes was previously estimated from Baa Atoll based on this surface area (Sattar, 2008). Yield per km^2 derived from these values comes to 0.63 tonnes considering the entire reef and lagoons, or 2.6 if we consider only the surface of productive fished reef flats, slopes and passes where most of the fishing occurs (Sattar et al., this issue). The reef fishery within the atoll caters for the various resorts in the Atoll as well as the export industry, whereas the grouper fishery solely targets the grouper export industry.

This paper reports on a conventional tagging study of reef fish. The objectives were to characterize the movements and distribution of reef fish within Baa Atoll. Results from this project, together with fishermen interviews in order to identify reef fish aggregations, will enable us to identify areas of importance to aid reef fishery management on the long term, specifically by identifying areas which could be made into time-area closures during spawning periods.

METHODOLOGY

Tagging was carried out in two phases; two weeks in August 2008, followed by two weeks in February 2009. Tagging was conducted during daily commercial fishing trips (n=28). Fishermen of B. Kudarikilu (outlined blue circle in Figure 2) were the focus. Although the initial plan was to tag equal numbers of the most commonly exploited species such as *Aprion virescens, Caranx melampygus, Lutjanus bohar, Lethrinus microdon* and *Lethrinus olivaceus,* this proved difficult. These species were not caught in equal quantities. Tagging effort was hence carried out according to the successful catch and release rates achieved for the most commonly caught species.

Fishing was carried out using either handlines or drop lines. In contrast with handlines, drop lines are weighted with a lead sink at the end, which enables the lines to drop down to depths. Individuals which were in good health when hauled on board were tagged and released. Individuals to be tagged were laid on a tagging bed with a measuring tape pasted on it for rapid length measurement. The fish were tagged about half-inch below the base of their dorsal fin, using conventional yellow dart tags (Fig. 1). Detailed information for all tagged individuals (tag number, species, length, weight, date and location of release) were recorded as soon as each individual was tagged.

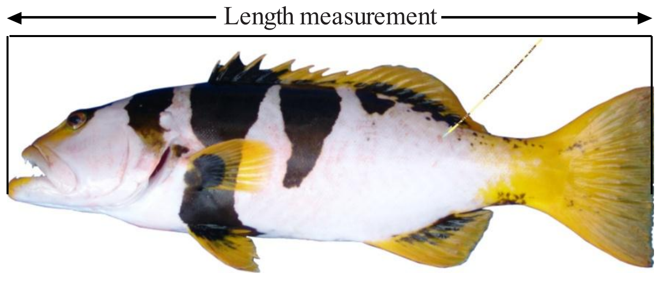

Figure 1. Illustration of the position of tagging

Precautions were taken to handle the fish very carefully so as to minimize stress while tagging and thus increase the chances of post-tagging survival. The eyes of the fish were covered, while tagging was carried out, since this had a calming effect on the individual. Once tagged, the fish was gently released back into the water, head-first. Tagging was mainly carried out on individuals which were larger than 30 cm, to ensure a higher survival after release.

A total of 408 individuals, mainly *A. virescens* and *C. melampygus* were tagged and released from different locations in Baa and Raa Atoll, as depicted in Figure 2. Released individuals were paid at a rate of MRF 15 per kilo (approx. US$ 1.2/kilo). Tag releases with inaccurately noted GPS positions have been eliminated from Figure 2.

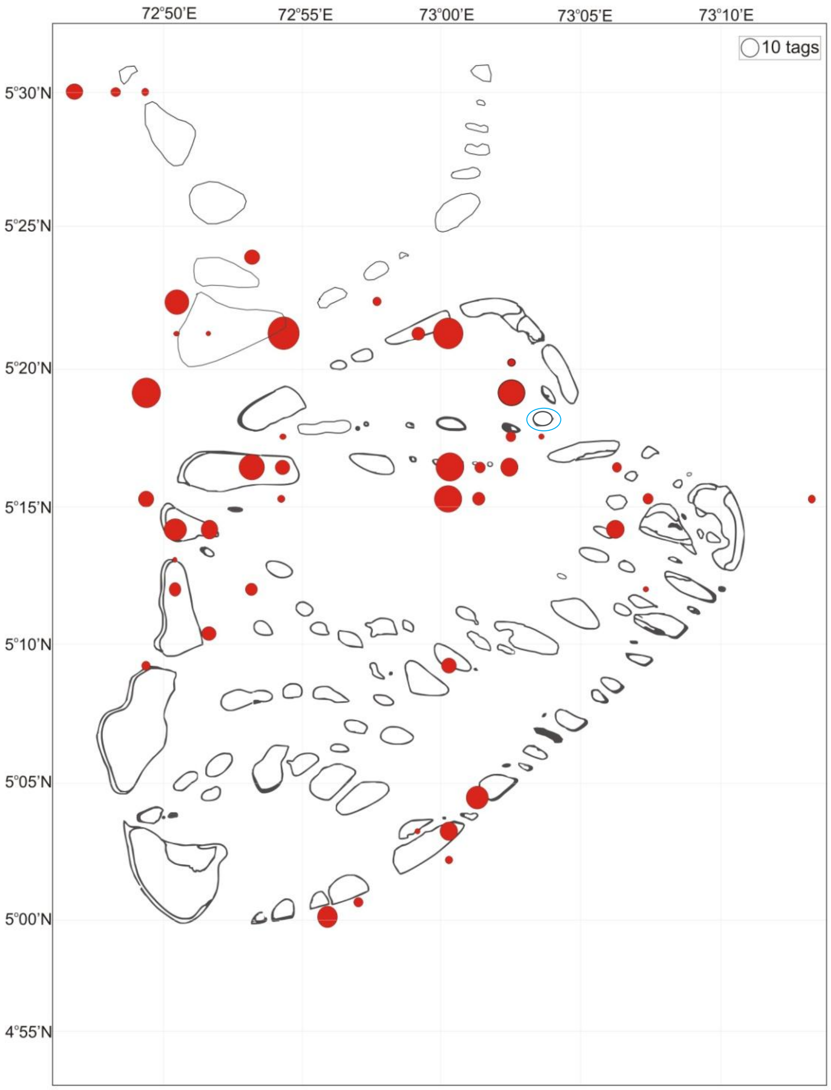

Figure 2. Locations of tag releases for 408 fishes. (Point of release is shown as the central point of the circles. The area of the circle is proportional to the number of tags released (see legend on the upper right corner, for 10 tags). If tags have been released from points very close to each other, these have been aggregated into one point.

This project was publicized throughout the entire Baa Atoll with the aid of posters. They provided clear instructions on how and where to return recaptured tags. Recaptured tags were to be returned to the Marine Research Centre with a completed "Tag recovery form". Fishermen were informed on how to measure the length of the recaptured individual and were also provided with measuring tapes for this purpose. A reward of MRF 150 (approximately US$ 12) was given for every tag recovered/returned with complete information. Tag recapture data was collected till September 2009.

RESULTS

Species Composition of Total Catch and Tagged Individuals

A total of 1345 individuals were sampled during the survey. Table 1 shows the species distribution of catch as well as the percent of total catch tagged for each species tagged. Most data shown further in this paper will come from the species caught in higher numbers such as *A. virescens* and *C. melampygus*. Species such as *Elagatis bipinnulata* and *Gymnosarda unicolor* were captured but not tagged since they are not true reef species.

Size Composition of *A. virescens* and *C. melampygus*

Figures 3 and 4 show the length distributions of the tagged individuals and the total catch for *A. virescens* and *C. melampygus* respectively. Mean lengths of total catch and tagged individuals were very close for both species. Figures show that mean lengths and length distributions for both categories were almost similar. This indicates that tagged individuals represent well the population of individuals caught for each species. It also shows that the tagging effort captured size classes frequently caught and not the largest or smallest size classes.

Tag Recoveries

A total of 44 individuals (details summarized in Table 2) were recaptured and reported, giving a recovery rate of 10.8%. This is relatively low, when taking into consideration the hypothesis that reef fish do not travel large distances and mainly remain within their atolls. Furthermore there is a relatively high fishing intensity within the atoll i.e. regular daily fishing by few village islands, plus recreational fishing by locals and tourists. We believe that a large number of individuals that were recaptured went unreported, according to conversations with recreational fishing vessels from resorts and other fishermen. This is indicative of the importance of increasing awareness and creating greater publicity before similar research projects are launched. Also contributing to low recaptures could be tag shedding by fishes or the movement of some of the tagged individuals away from the atoll or fishing areas.

Table 1. Species distribution of total catch and tagged individuals in percentage.

Scientific Name	**English Name**	**Dhivehi Name**	**Tagged % of total catch**	**Total catch percent**
Aethaloperca rogaa	Redmouth Grouper	Ginimas faana	0.07	0.82
Aphareus furca	Smalltoothed jobfish	Keyolhu rovvi	0.00	0.22
Aprion virescens	Green jobfish	Giulhu	10.63	25.20
Carangoides caeruleopinnatus	Coastal trevally	Vahboa handhi	0.15	0.22
Carangoides ferdau	Blue trevally	Dhabaru handhi	0.07	0.07
Carangoides orthogrammus	Island trevally	Thumba handhi	1.26	5.35
Caranx ignobilis	Giant trevally	Muda handhi	0.22	0.52
Caranx lugubris	Black trevally	Kalha handhi	0.07	0.07
Caranx melampygus	Bluefin trevally	Fani handhi	8.77	13.75
Caranx sexfasciatus	Bigeye trevally	Haluvimas	0.74	0.74
Cephalopholis miniata	Coral hind	Koveli faana	0.00	0.37
Cephalopholis sonnerrati	Tomato hind	Veli faana	0.00	0.07
Coryphaena equiselis	Pompano dolphinfish	Aila	0.00	0.07
Elagatis bipinnulata	Rainbow runner	Maaniyamas	0.00	26.54
Epinephelus flavocaeruleus	Blue and Yellow grouper	Dhon noo faana	0.07	0.22
Epinephelus fuscoguttatus	Brown marbled grouper	Kas faana	0.15	0.15
Epinephelus polyphekadion	Camouflage grouper	Kula faana	0.00	0.07
Fistularia spp.	Cornetfish	Tholhi	0.00	2.75
Gnathodon speciosus	Golden trevally	Libaas handhi	0.00	0.15
Gymnosarda unicolor	Dogtooth tuna	Voshimas	0.00	5.95
Katsuwonus pelamis	Large skipjack tuna	Godhaa	0.00	0.07
Lethrinid spp. (to be identified)	Maldivian emperor	Laaboa kalhihi	0.30	0.30
Lethrinus conchyliatus	Redaxil emperor	Thun raiy filolhu	0.52	0.59
Lethrinus microdon	Small tooth emperor	Thundhigu filolhu	0.89	1.49
Lethrinus nebulosus	Spangled emperor	Filolhu	0.15	0.15
Lethrinus olivaceus	Longnose emperor	Filolhu	2.08	3.27
Lethrinus rubrioperculatus	Spotcheek emperor	Kalhihi	0.30	0.30
Lethrinus xanthochilus	Yellowlipped emperor	Thun reendhoo filolhu	0.59	0.89
Lutjanus bohar	Red snapper	Raiymas	2.30	3.72
Lutjanus gibbus	Humpback snapper	Ginimas	0.15	0.45
Macolor macularis	Midnight snapper	Kalhu foniyamas	0.00	0.30
Macolor niger	Black and white snapper	Foniyamas	0.45	0.45
Plectropomus areolatus	Squaretail coral grouper	Olhu faana	0.07	0.30
Plectropomus laevis	Black-saddled coral grouper	Kula olhu faana	0.07	0.52
Plectropomus pessuliferus	Roving coral grouper	Dhon olhu faana	0.15	0.37
Sphyraena forsteri	Bigeye barracuda	Faru tholhi	0.00	0.74
Thunnus albacares	Yellowfin tuna	Reendhoo uraha kanneli	0.00	1.64
Variola albimarginata	Whitedged lyretail	Kanduraiy haa	0.00	0.07
Variola louti	Moontail sea bass	Kanduhaa	0.07	1.04

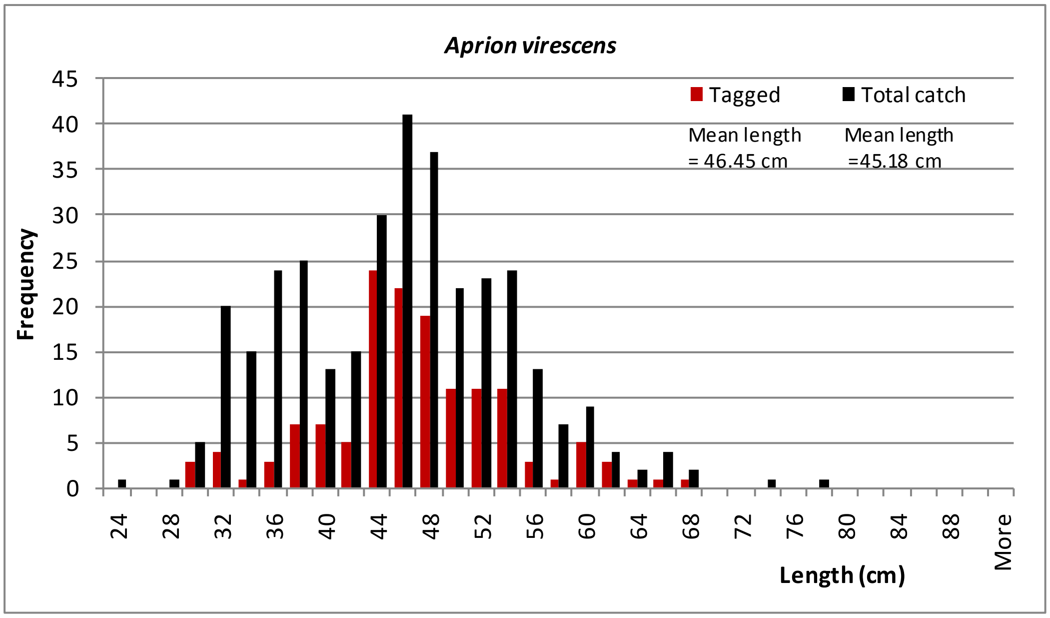

Figure 3. Length frequency distributions of all caught and tagged individuals of *A. virescens.*

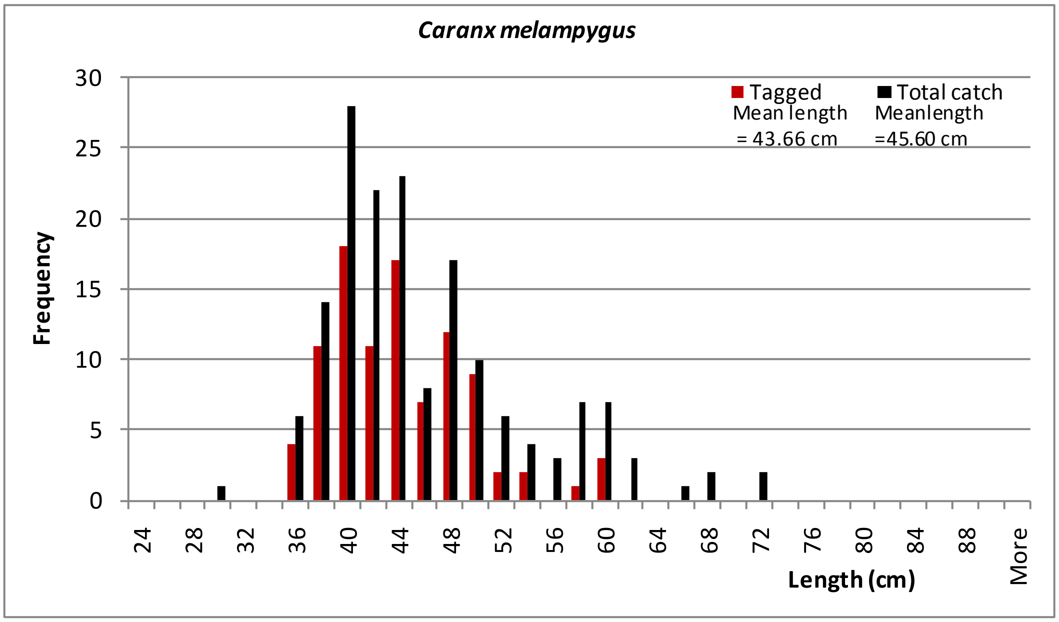

Figure 4. Length frequency distributions of all caught and tagged individuals of *C. melampygus.*

Tag Recoveries

A total of 44 individuals (details summarized in Table 2) were recaptured and reported, giving a recovery rate of 10.8%. This is relatively low, when taking into consideration the hypothesis that reef fish do not travel large distances and mainly remain within their atolls. Furthermore there is a relatively high fishing intensity within the atoll i.e. regular daily fishing by few village islands, plus recreational fishing by locals and tourists. We believe that a large number of individuals that were recaptured went unreported, according to conversations with recreational fishing vessels from resorts and other fishermen. This is indicative of the importance of increasing awareness and creating greater publicity before similar research projects are launched. Also contributing to low recaptures could be tag shedding by fishes or the movement of some of the tagged individuals away from the atoll or fishing areas.

Table 2. Summary data of recaptured individuals (numbers in brackets indicate range).

Species	No. recaptured	Mean size of tagged inds.(cm)	Mean time at liberty (days)	Mean distance travelled (km)
A. virescens	27	50 (35 - 65)	74 (2 - 385)	4 (0 - 22)
C. melampygus	5	45 (42 - 53)	46 (7 - 93)	5 (0.7 - 17)
C. sexfasciatus	2	60 (58 - 62)	13 (10 - 17)	1 (0 - 3)
L. bohar	5	35 (27 - 45)	48 (11 - 109)	2 (0 - 9)
L. olivaceus	2	44 (40 - 49)	100 (90 - 110)	0.5 (0.4 - 0.6)
L. xanthochilus	1	47	2	0.9
M. niger	1	56	36	0.9
P. laevis	1	36	20	1.9

On a species level, 27 individuals of *A. virescens* were recovered (Table 2), yielding a recovery rate of 18.9% for this species. In comparison to the success rates observed in 12 years in the reef fish tagging study carried out in Florida, our rates appeared quite significant for a 1 year period. Figure 5 shows the release and recovery points for all the recovered tags which have been returned with complete information. The red points indicate location of release and the blue points refer to the recovery locations. Arrows connect the release and recovery points for each tag with the arrowhead showing the direction of movement. A close up of the area where most tags were recovered from is shown in Figure 6.

Distance Travelled

Figure 7 shows the frequency distribution of distance travelled by all recaptured reef fish in Table 1, and specifically for *A. virescens*, between the time of release and recapture. Although distance between the points of release and recovery can be calculated, conventional tagging does not enable the delineation of the actual path of movement. Thus the distance travelled calculated denotes the least distance travelled by individuals during their time at liberty. The least distance travelled was calculated using a modification of Vincenty formula for calculating distance between two latitude longitude points (http://bluemm.blogspot.com/2007/01/excel-formula-to-calculate-distance.html, website accessed September 2009) which was further verified using GPS visualizer (http://www.gpsvisualizer.com/, website accessed August 2009), an online utility which creates maps and profiles using GPS data.

These results support the assumption that the majority of individuals tagged did not travel large distances. Instead, they remained within the same reef area. Mean distance travelled by *A. virescens* and *C. melampygus* was approximately 4 and 6 km respectively. A detailed look at distances travelled by *A. virescens*, shows that although 42% were recovered from a distance of 1 km or less from the point of release, 30% were recovered from distances greater than 5 km from the point of release. Furthermore, one individual of this species was recovered from a distance of 22 km from the point of release and was noted to have crossed the ocean between Baa and Raa atolls. Travel to such large distances by some individuals is indicative of the fact that some of the un-recaptured tagged individuals might have moved to other nearby atolls.

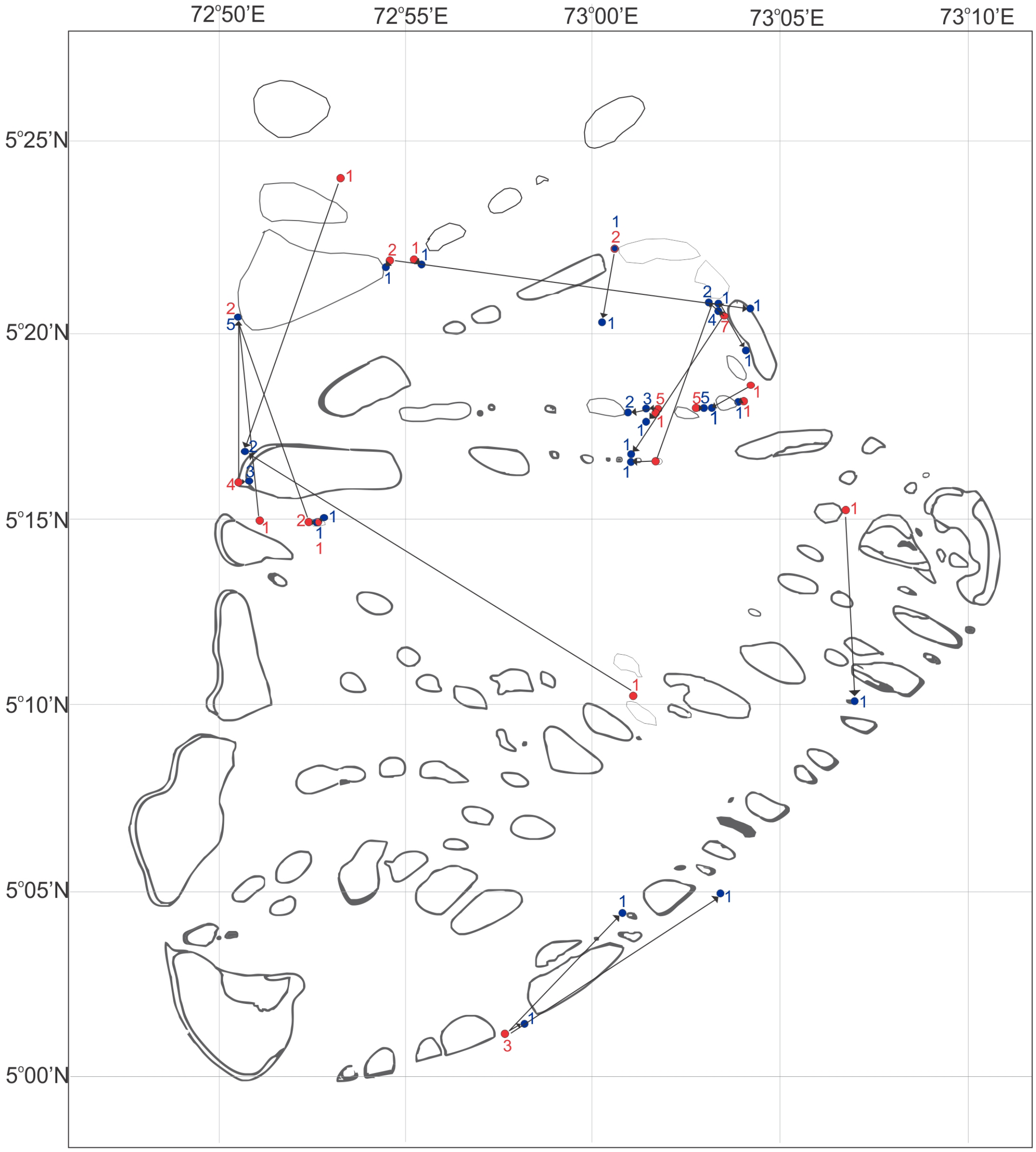

Figure 5. Points of release (red) and recovery (blue) of all recovered and returned tags. The arrowheads show the direction of movement. Numbers indicate number of tags released (red) and/or recovered (blue) for each point

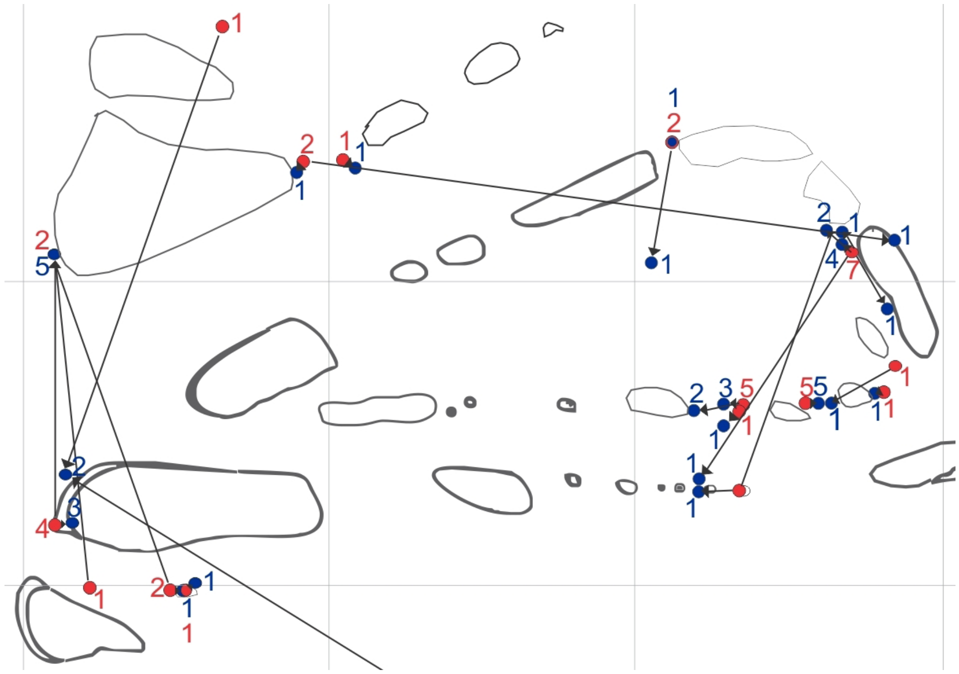

Figure 6. Close-up of area where most tags were recovered. Arrows indicate direction of movement and numbers indicate number of tags released (red) and/or recovered (blue) for each point.

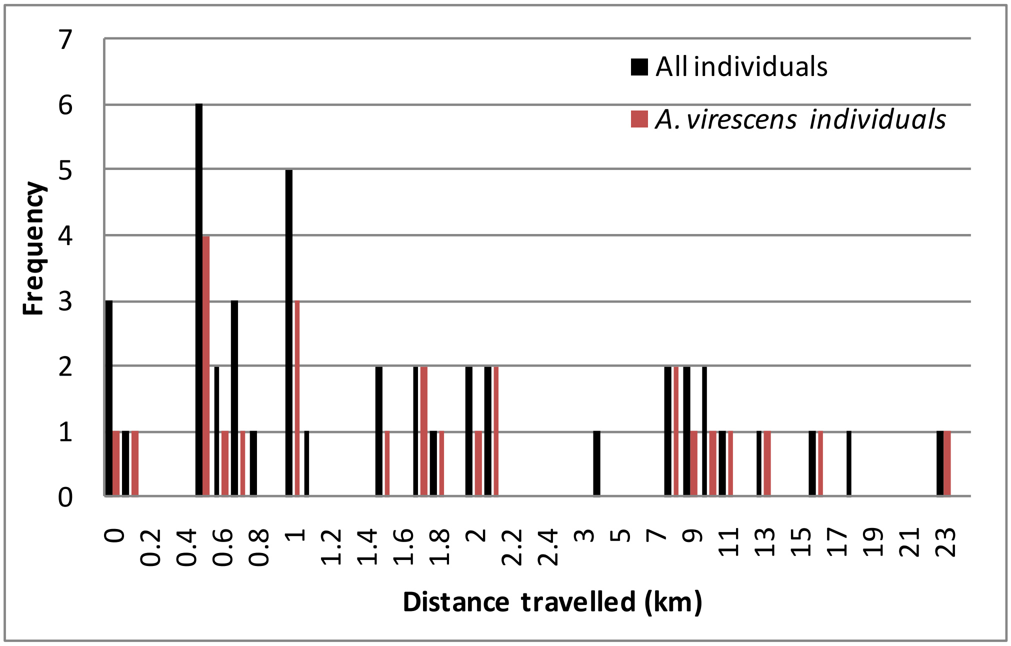

Figure 7. Least distance travelled by all species individuals (black) and individuals of *A. virescens* (red) recovered and reported. Note: X-axis not continuous.

Time at Liberty

Time at liberty (length of time between release and recapture of individuals) varied for different species, ranging from 2 to 385 days. Average time at liberty for all species was 63 days.

Since most individuals were recaptured from locations close to their release points, it is likely that majority would have been caught within a short time frame of being released. With respect to this, there were two obvious peaks in recaptures both during the first week of release and again 3 months of release. This is indicative of potential movement of the individuals during their time at liberty, though we cannot determine the exact total distances travelled. Although we could expect a directly proportional relationship between time at liberty and distance travelled, Figure 8 negates this assumption. Further, the individual of *A. virescens* which was recovered 385 days after release was recovered only approximately 2 km from the point of release, in the same reef area. On the other hand, another individual of *A. virescens* recovered 107 days after release, was 22 km away from the point of release, indicating significant movement during its time at liberty.

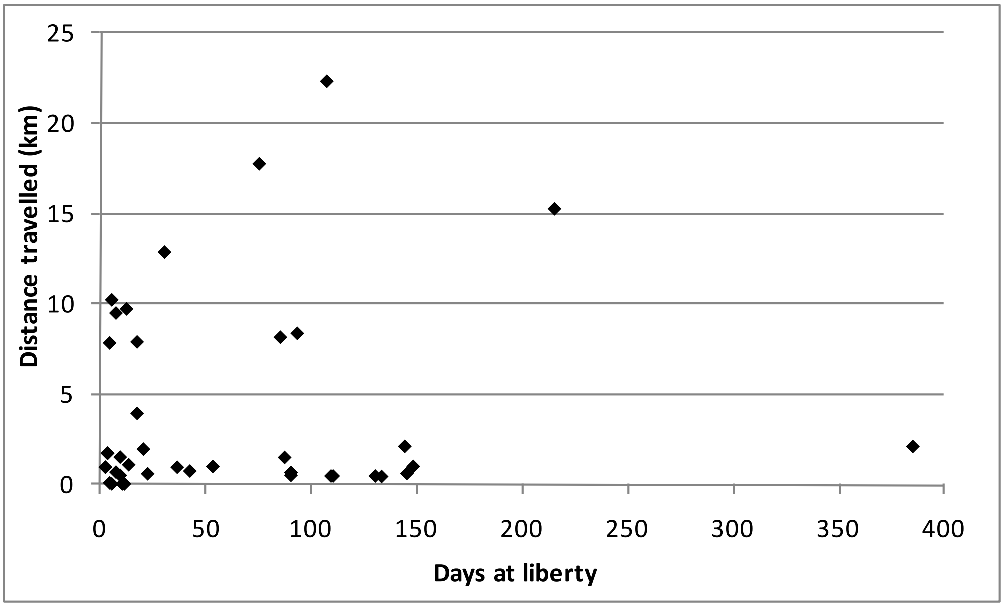

Figure 8. Correlation between time at liberty and distance travelled by all recaptured individuals.

DISCUSSION AND CONCLUSION

The most commonly tagged species, in proportion to catch quantities, were *A. virescens* and *C. melampygus*. The decision to tag individuals larger than 30 cm eliminates the smaller individuals which are more susceptible to predation. Additionally, tagging of larger individuals was minimized to reduce loss of tags due to natural mortality. These precautions ensured that there would be a good return of tags, by tagging size classes vulnerable to fishery.

Thanks to these precautions, the level of tag recovery achieved for Baa was fairly successful with an average recovery rate of 10.8% for all species and 18.9% for *A. virescens* over a 1 year period. In comparison, reef fish tagging study conducted in Florida reported a 7.7% return rate for the Red grouper, *Epinephelus morio* (Burns, 2009), and species-specific recovery rates of 50% for some species, but over a 12-year period (http://isurus.mote.org/research/cfe/fish-bio/tagging-reef_fish.htm, website first accessed March 2008).

There are several reasons that could explain a low recovery rate: lack of awareness amongst stakeholders, natural mortality, discarded/unreported tags, low exploitation rates, tags not being seen by the fishermen and tag shedding. From these, we suggest that the most plausible reason in the Baa pilot study is the lack of awareness amongst the fishermen (especially those of neighbouring atolls) and other stakeholders with respect to the aims and importance of the project. It is recommended that future tagging studies address these issues and also consider studying tag shedding rates which are useful in estimating accurate recovery rates.

Results from this pilot project, indicates that reef fish species such as *A. virescens* and *C. melampygus* were mainly resident and did not seem to travel far from their home reefs. Although the majority of tags were recovered from locations close to where they were released, a small number of tags were recovered from distances as far as 22 km away from their release locations. Of course, we are not able to infer the path of movement between release and recapture, thus we cannot conclude that an individual recaptured from the same area of release, had not moved from the reef for the duration of its time at liberty, to go to spawn or feed elsewhere. The correlation between distance travelled and time at liberty did not suggest an increase in distance travelled with increasing time at liberty. Other technology, like deployment of networks of acoustic sensors would be needed to qualify the paths followed by the tagged individuals (Chateau and Wantiez, 2009).

High rates of recovery in similar locations could suggest that these sites act as concentrations areas, for spawning or feeding. Here, this trend is not obvious, and more tagging would be needed. Figures 5 and 6 may suggest accumulations of individuals next to some passes, but this can not be established with certainty despite the fact that these sites are consistent with reported spawning aggregation sites by fishermen from Baa atoll and other atolls during the Reef fish Aggregation Identification interviews carried out by IUCN in 2007/2008 (Tamelander et al., 2008). It is recommended that immediate action be taken to confirm the likely spawning aggregations identified by fishermen surveys and this project, with in-water surveys. This would enable establishment of MPAs on critical areas for species resilience. Continuous high fishing pressure on these sites is a threat to the populations which aggregate at these sites. High fishing pressure on spawning/feeding aggregations impact both number of aggregations and number of individuals per aggregation (Sadovy and Domeier, 2005). While there has been no formal spawning aggregation research done in Maldives, fishermen have reported seeing fewer individuals at aggregation sites, during the spawning period, in comparison to previous years. Therefore identification and verification of these areas and as well as their potential use would offer the foundation for sound management decisions (quotas, seasonal/temporal closures, Marine Protected Areas). Effective implementation and benefits of these MPAs would be strengthened by increased awareness of the issues among both stake holders and the public at large.

Taking into account all the limitations of this project, it can be concluded that commercial reef fish species of the Maldives have a short "home range". This could imply that in a country such as the Maldives, where the geographic formation is such that communities are divided by atolls and islands, conservation of our resources can also be carried out by delineating whole atolls as conservation units on their own. However, we have to take into consideration, the dispersal of planktonic larvae and 'source-sink' connections between atolls.

ACKNOWLEDGEMENTS

The authors thank AECP for providing the funds necessary to carry out the project. We would especially like to thank Dr. Charles Anderson for his critical remarks towards improving this manuscript. We would also like to thank all MRC staff who participated in the field trips and Ahmed Riyaz Jauharee, Steve Lindsay, Ahmed Najeeb and Serge Andréfouët for their comments to various draft versions of the manuscript. Much gratitude also to the fishermen of B. Kudarikilu for their constant support and cooperation towards our various research programmes.

REFERENCES

Atoll Ecosystem Conservation Project, viewed 2010
<http://www.biodiversity.mv/aec/>
GPS Visualizer, viewed August 2009
http://www.gpsvisualizer.com/
BlueMM, *BlueMM Excel formula to calculate distance between 2 latitude, longitude (lat/lon) points (GPS positions),* viewed September 2009
<http://bluemm.blogspot.com/2007/01/excel-formula-to-calculate-distance.html>
Almany, G.R., M.L. Berumen, S.R. Thorrold, S. Planes and G.P. Jones
2007. Local replenishment of coral reef fish populations in a marine reserve. *Science* 316: 742-744
Bolden, S.K.
2000. Long distance movement of a Nassau grouper (Epinephelus striatus) to a spawning aggregation in the Central Bahamas. *Fishery Bulletin* 98: 642-645
Burns, K.M.
2009. Evaluation of the efficacy of the minimum size rule in the red grouper and red snapper fisheries with respect to J and circle hook mortality and barotrauma and the consequences for survival and movement. Unpublished Doctoral dissertation. School of Marine Science, University of South Florida, Tampa, Florida, USA. 184 pp.

Chateau, O., and L. Wantiez.

2009. Movement patterns of four coral reef fish species in a fragmented habitat in New Caledonia: implications for the design of marine protected area networks. *ICES Journal of Marine Science* 66:50-55.

Naseer, A. and B. G. Hatcher

2004. Inventory of the Maldives' coral reefs using morphometrics generated from Landsat ETM+ imagery. *Coral Reefs* 23:161-168.

Newton, K., I. M. Côte', G. M. Pilling, S. Jennings and N. K. Duly

2007. Current and future sustainability of Island Coral Reef Fisheries. *Current Biology* 17:655-658

Sadovy, Y. and M. Domeier

2005. Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. *Coral Reefs* 24(2):254-262

Sattar, S. A.

2008. *Reef fishery Survey 2006-2007*. Marine Research Centre, Male'.

Tamelander J., S. Sattar, S. Campbell, V. Hoon, R. Arthur, E.J.K. Patterson, U. Satapoomin, M. Chandi, A. Rajasuriya and M. Samoilys

2008. Reef Fish Spawning Aggregations in the Bay of Bengal: Awareness and Occurrence. *Proceedings of the 11th International Coral Reef Symposium.* Ft. Lauderdale, Florida. 7-11 July 2008

Waheed A. and R. C. Anderson

1994. The Maldivian tuna tagging programmes. Pages 211-216 in J. D. Ardill (ed) Proceedings of the Fifth Expert Consultation on Indian Ocean Tunas, Mahe, Seychelles October 1993.

Yesaki, M. and A. Waheed

1992. Results of the tuna tagging programme conducted in the Maldives during 1990. IPTP/92/WP/24. Indo-Pacific Tuna Development and Management Programme, Colombo.

SPATIAL VARIATION IN OTOLITH CHEMISTRY OF *EPINEPHELUS MERRA* IN BAA ATOLL, MALDIVES

BY

GERALDINE CRIQUET,[1] LAURENT VIGLIOLA,[2] AND PASCALE CHABANET [1]

INTRODUCTION

The particular geography of Maldives archipelago induces that the economy is essentially dependant on marine resources. Despite the fact that pelagic resources are the most exploited, reef fin fishery strongly increased due to tourism and export industry development in the last decades (Sattar *et al.*, this issue). Although there are no clear signs of overexploitation and decline of fish population overall, Sattar et al. (this issue) have concerns for some groupers species in some locations. Chabanet *et al.* (this issue) also report no sighting of sharks in Baa for instance. Thus, Maldivian government and stakeholders remain vigilant, and several MPAs were established in various atolls. The goal of the Atoll Ecosystem Conservation Project (http://www.biodiversity.mv/aec/) aims to establish a network of conservation for Baa atoll for instance.

Anthropogenic activities have strongly affected coral reef ecosystems worldwide and Marine Protected Areas (MPAs) are increasingly considered as an effective tool for fishery management (Roberts *et al.*, 2001) and biodiversity conservation (Micheli *et al.,* 2004). To design MPAs and soundly manage fish stocks, it is vital to obtain information on connectivity between populations, migration and movement, and describe population dynamics. A variety of methods have been used to assess movements between populations such as population genetic (Bradbury *et al.*, 2008), hydrodynamic and lagrangian dispersal models (Cowen *et al.*, 2000), external tags (Willis *et al.*, 2001, Sattar *et al.*, this issue), acoustic telemetry (Topping *et al.*, 2005) or transgenerational marking of embryonic otolith (Thorrold *et al.*, 2006). Recently, elemental composition of fish otoliths has been successfully used to examine connectivity between populations (Milton and Cheney, 2001; Chittaro *et al.*, 2006). Elemental chemistry is used because trace elements from the environment are incorporated into the otolith during growth and the otolith is metabolically inert (Campana, 1999). According to Hamer *et al;*(2003), the success of using otolith chemistry to measure connectivity would be dependant on a detectable level of chemical variation at biologically relevant spatial scales.

The present study investigated whether otoliths of *Epinephelus merra* collected from different coral reefs in Baa Atoll could be discriminated on the basis of multielemental chemistry. The study aimed at evaluating the potential of otolith microchemistry technique to study connectivity among reefs at Baa Atoll, and brings on the long run key data for MPAs selection.

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MATERIAL AND METHODS

Study Site and Sampling

The Republic of Maldives is an archipelago of 26 atolls located in central Indian Ocean. Baa Atoll, circa 40 km long and wide, is located in the western side of the Maldives archipelago and ranges from 4°49’N and 5°23’N and 73°06’E (Fig. 1).

The survey presented here took part during a biodiversity census survey conducted in May-June 2009, on lagoon and outer slope habitats in Baa Atoll (Fig. 1). For this study, a total of 93 *E. merra* were collected at 6 stations: stations 3 and 28 (lagoon reef flat), 6 and 21 (lagoon reef slope), 17 (pass slope) and 20 (reef flat under oceanic influence). Fish were stored in ice immediately after capture and dissected within one hour of collection.

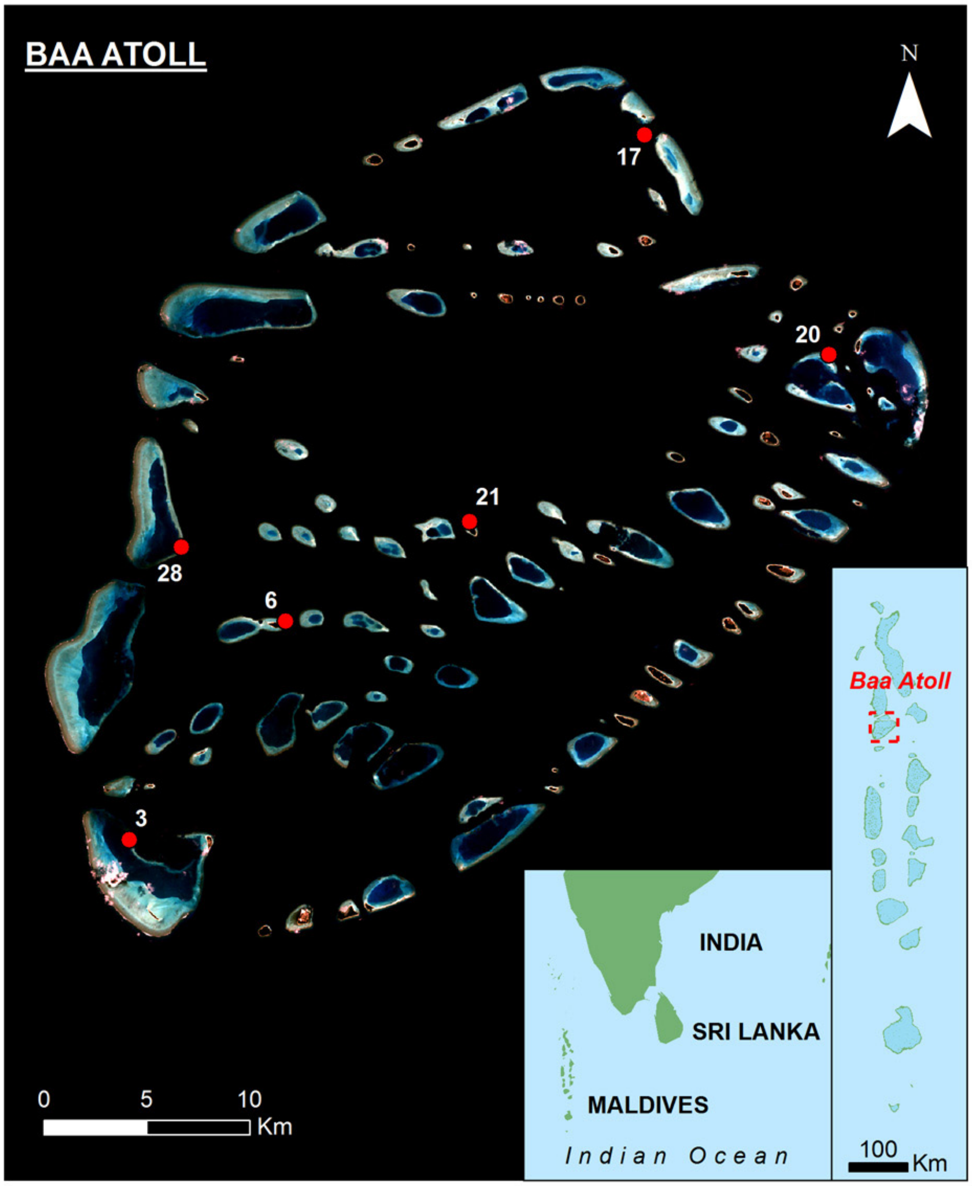

Figure 1. Map of Baa Atoll and position of *E. merra* sampling stations.

Laboratory Analysis

For each individual, total length (TL) was measured to the nearest mm and sagittal otoliths were extracted with acid-washed plastic tweezers, cleaned of adhering tissues in ultrapure water and stored dry in acid-washed eppendorf tubes. At the lab, otoliths were cleaned of organic material by soaking in an equal-volume mixture of 30% ultrapure H_2O_2 and 0.1 mol L^{-1} ultrapure NaOH for 1 hour. Each otolith was then ultrasonicated for five minutes and rinsed with ultrapure water and individually soaked in five separated 5-min baths of ultrapure water. After the fifth bath, otoliths were air-dried in a HEPA-filtered class 100 laminar flow hood. Whole otoliths were placed on double-sided tape just before laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) analysis (Warner *et al.*, 2005).

Ten otoliths per station were randomly chosen (except for station 6, N=3) and ablated with the LA-ICPMS at the edge of otolith postrostrum. All analyzes were conducted at the University of Montpellier 2 (UMR 5243 Geosciences), using a 193 nm Excimer Laser System (CompEx 102, LambdaPhysiks) coupled to a Element XR sector field ICPMS 5thermoFisher). For all otoliths, the laser beam diameter was set at 51 µm and the laser was operated with a repetition rate of 4 Hz at 15 $J.cm^{-2}$. Helium was used as the ablation gas, to enhance sensitivity and reduce particle condensation on the surface. An Argon gas flow was then admixed to the laser-generated aerosol, prior to introduction into the ICPMS for elemental analysis. The instrument was operated in low mass resolution and calcium was used as an internal standard using a stoichiometric value of 56% CaO. A standard reference glass material (NIST 612) was used to calibrate analyzes and to control for instrumental drift. Apart from Ca, 20 elements were measured: Li, B, Mg, Ti, Cr, Mn Co, Ni, Cu, Zn, Rb, Sr, Mo, Cd, Sn, Ba, Ce, Pb, Th and U. Calculation of drift and limits of detection (LOD) were made off-line using the Glitter software. Elements for which 25% of the measures were below LOD irrespective of fish origin were removed from further analysis. Remaining elements were: Li, B, Mg, Mn, Co, Ni, Zn, Sr, Cd, Sn and Ba. Data were expressed as ratios to calcium and element concentration below LOD were set to zero.

Statistical Analysis

We used discriminant function analyses (DFAs) to examine spatial patterns of multielemental chemical signature of otoliths. Element ratios that contributed most to the discrimination among sites (Sr/Ca, Mg/Ca, Mn/Ca and Ba/Ca) were further analyzed by non-parametric ANOVAs (Kruskall-Wallis) in order to investigate spatial differences.

RESULTS AND DISCUSSION

There was no significant difference in fish total length between sampling stations (Table 1).

DFA successfully reclassified 98% of the individuals (Cohen-kappa test) and some spatial structure was apparent (Fig. 2). The first discriminant function (Wilk's $\lambda < 0.001$, $P < 0.001$) distinguished fishes from lagoon reef flat (stations 3 and 28) to individuals from reef flat under oceanic influence (station 20) and from lagoonal and pass slope (station 21, 17 and 6). The second discriminant function (Wilk's $\lambda = 0.009$, $P < 0.001$) separated fishes from reef slope into two groups: on one hand fishes from lagoon reef slope (station 21) and on the other hand fishes from outer reef pass slope (station 17) and from lagoon reef slope (station 6).

Greatest contributors to the discrimination among sites were Sr, Mn, Mg and Ba and their ratios to calcium are given for each station in Table 2. Significant differences in concentration among sites were observed for Mg/Ca and Ba/Ca ($P < 0.05$) but not for Sr/Ca and Mn/Ca. Fish otoliths from lagoon reef flat (station 3 and 28) were characterized by a higher Mg/Ca and Ba/Ca ratios than the others. The same pattern was lightly observed for Sr/Ca and Mn/Ca..

Table 1. Results of ANOVA on fish total length. Mean size (cm) and standard error are given for each station.

Stations	Mean size	df	F	P
All stations	15.69±0.204	5	0.385	0.858
3	15.06±0.502			
6	15.86±1.004			
17	15.96±0.494			
20	15.73±0.435			
21	15.74±0.437			
28	15.79±0.456			

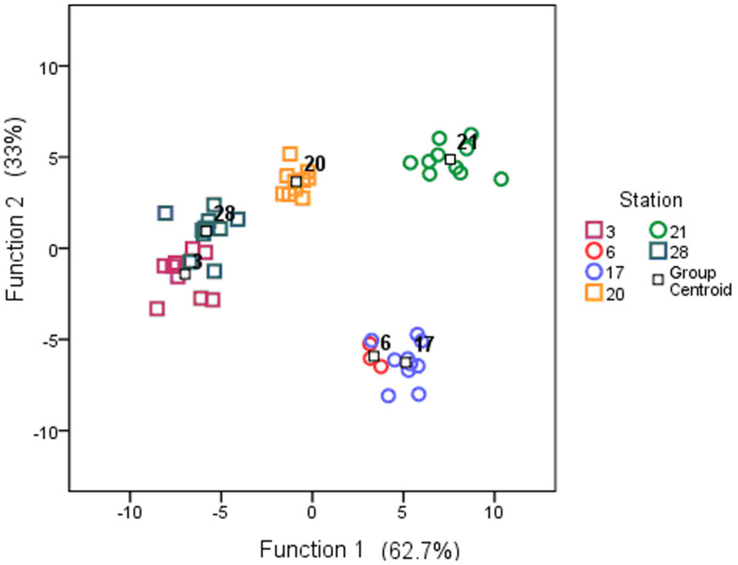

Figure 2. Discriminant function analysis (DFA) achieved with the multielemental chemical signature (Li, B, Mg, Mn, Co, Ni, Zn, Sr, Cd, Sn and Ba) of *E. merra* otoliths from different stations of Baa Atoll. Squares represent reef flat and circles represent reef slope.

Table 2. Mean and standard error of trace element ratios for each station.

	Stations					
	3	6	17	20	21	28
Sr/Ca	11.26±3.45	1.11±0.05	4.61±2.34	3.28±2.12	5.76±3.02	7.14±3.042
Mg/Ca	11.71±3.94	0.12±0.02	2.98±1.69	2.36±2.16	5.06±3.20	24.13±11.14
Mn/Ca	8.91±2.98	0.08±0.03	3.82±2.48	2.15±2.02	4.95±3.07	5.63±2.68
Ba/Ca	0.035±0.001	0.006±0.001	0.021±0.004	0.010±0.002	0.012±0.003	0.074±0.045

Our results showed that *E. merra* captured in Baa Atoll different habitats may be differentiated based on their otolith chemistry. We found a clear discrimination between otoliths of fishes from lagoon reef flat stations and lagoonal-pass slope stations, with higher trace element ratios for the first. These findings could derive from contrasting differences in environmental conditions of those stations. In fact, some environmental characteristics such as water temperature and salinity are likely to have direct effects on the concentration of some elements (Sr) in the water that affects otolith elemental composition (Gillanders and Kingsford, 2000). In the present study, we have no data on the environmental characteristics of each station (water temperature, salinity and chemistry) to support this hypothesis. Endogenous factors (diet, stress, ontogenetic effects...) can also influence otolith elemental composition, but we minimized some of these effects by analyzing otoliths of fishes with similar sizes.

The analysis of multielemental composition along *E. merra* otolith growth axis (juvenile part to adult part) may be conducted to determine the origin of fishes and to reconstruct their movement's history within Baa Atoll. However, temporal stability of elemental signature of otoliths (Gillanders and Kingsford, 2003; Ruttenberg *et al.,* 2008) of *E. merra* at Baa Atoll should first be investigated.

In conclusion, multielemental composition of fish otoliths showed a good potential to measure connectivity between populations within an atoll at local spatial scale, and the technique may be useful on the long run for the design of MPAs and the management of fisheries.

ACKNOWLEDGEMENTS

This study was funded by the French Fondation pour la Recherche sur la Biodiversité, Program "Biodiversity of Indian Ocean Islands" and by the Atoll Ecosystem Conservation Project. We thank Lionel Bigot for his help for capture of fishes, Olivier Bruguier for the use of ICP-MS and Audrey Darnaude and Franck Ferraton for the help for the preparation of samples. We acknowledge Serge Andréfouët and Shiham Adam at the Marine Research Center for the organization of the surveys and the management of the project.

REFERENCES

Bradbury, I.R., S.E. Campana, and P. Bentzen
2008. Estimating contemporary early life-history dispersal in an estuarine fish: integrating molecular and otolith elemental approaches. *Molecular Ecology* 17: 1438-1450.

Campana, S.E.
1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Marine Ecology Progress Series* 188: 263-297.

Chittaro, P.M., P. Usseglio, B.J. Fryer and P.F. Sale
2006. Spatial variation in otolith chemistry of *Lutjanus apodus* at Turneffe Atoll, Belize. *Estuarine Coastal and Shelf Science* 67: 673-680.

Cowen, R.K., K.M.M. Lwiza, S. Sponaugle, C.B. Paris and D.B. Olson
2000. Connectivity of marine populations: open or closed? *Science* 287: 857-859.

Gillanders, B.M. and M.J. Kingsford
2000. Elemental fingerprints of otoliths of fish may distinguish estuarine “nursery” habitats. *Marine Ecology Progress Series* 201: 273-286.

Gillanders, B.M. and M.J. Kingsford
2003. Spatial variation in elemental composition of otoliths of species of fish (family Sparidae). *Estuarine Coastal and Shelf Science* 57: 1049-1064.

Hamer, P., G.P. Jenkins and B.M. Gillanders
2003. Otolith chemistry of juvenile snapper *Pagrus auratus* in Victorian waters; natural chemical tags and their temporal variation. *Marine Ecology Progress Series* 263: 261-273.

Micheli, F., B.J. Halpern, L.W. Botsford and R.R. Warner
2004. Trajectories and correlates of community change in no-take marine reserves. *Ecological Applications* 14: 1709-1723.

Milton D.A. and S.R. Cheney
2001. Can otolith chemistry detect the population structure of the shad hilsa *Tenualosa ilisha*? *Marine Ecology Progress Series* 222: 239-251.

Roberts, C.M., J.A. Bohnsack, F.R. Gell , J.P. Hawkins and R. Goodridge
2001. Effects of marine reserves on adjacent fisheries. *Science* 294: 1920-1923.

Topping D.T., C.G. Lowe and J.E. Caselle
2005. Home range and habitat utilization of adult California sheephead Semicossyphus pulcher (Labridae), in a temperate no-take marine reserve. *Marine Ecology* 147: 301-311.

Warner, R.R., S.E. Swearer, J.E. Caselle, M. Sheeby, G. Paradis
2005. Natl trace-elemental signatures in otolith of an open coast fish. *Limnology and Oceanography* 50: 1529-1542.

Willis, T.J., D.M. Parsons and R.C. Babcock
2001. Evidence for long-term site fidelity of a snapper (*Pagrus auratus*) within a marine reserve. *New Zealand Journal of Marine and Freshwater Research* 35: 581-590.

HABITAT MAPPING FOR CONSERVATION PLANNING IN BAA ATOLL, REPUBLIC OF MALDIVES

BY

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ABSTRACT

In order to propose spatially-explicit conservation strategies driven by biodiversity for Baa Atoll, habitat maps were created from LANDSAT and Quickbird satellite images. The LANDSAT derived habitat map described the atoll geomorphology following the Millennium Coral Reef Mapping Project typology, which is made of 5 different hierarchical levels. The Quickbird derived high spatial resolution habitat map is a map of both geomorphological and benthic hierarchical information. Benthic information comes from 24 field stations surveyed in May-June 2009 for this project, and from an independent survey that quantified forereef coral cover and dominant growth forms for all the reefs found in Baa Atoll in June 2008. The Quickbird derived habitat map is created to take advantage of this extensive data set, which minimizes mapping errors on forereefs. Other reef zones were also mapped by considering the hierarchical level (geomorphology and benthic if possible) that minimized photo-interpretation uncertainty. Both habitat maps were processed to display habitat richness for all virtual management units found along a regular grid (1 km^2-cell). The differences due to different spatial and thematic resolution are discussed.

INTRODUCTION

Habitat mapping in coral reef environments is now a routine activity supporting fishery management, biodiversity inventories, niche modeling, and conservation planning (Andréfouët 2008; Purkis et al., 2008; Hamel and Andréfouët 2010; Dalleau et al., 2010). Remote sensing data routinely offers the necessary synoptic spatial background, at very high spatial resolution, typically within a range of one to five meters (Andréfouët 2010). The limits of remote sensing data are now well established, the methods well documented, and very high spatial resolution sensors can achieved a high accuracy. However, there are always site-specific and application-specific aspects that may call for an adaptation of the methods to apply, an adaptation in the design of the habitat typology to map, and an adaptation of the accuracy assessment protocol (Gilbert et al., 2006).

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In coordination with the Atoll Ecosystem Conservation (AEC) project of Baa Atoll and the Marine Research Center of Maldives, we used habitat maps derived from remote sensing to stratify the biodiversity sampling (results reported in this volume by Bigot and Hamir, Andréfouët et al.; Payri and Mattio; Gravier-Bonnet and Bourmaud; Chabanet et al.) and to create spatially-explicit scenarios for conservation of habitats and biodiversity (Hamel and Andréfouët, this issue).

Here, we report on the specific aspects of the habitat mapping component of the Baa Atoll conservation project. We present the habitat survey and the resulting typology, the images used for the mapping, the specific principles used to map Baa habitats, and the mapped products.

MATERIAL AND METHODS

Field Data and Habitat Typology

Habitats were described in June 2009 for 24 sites across Baa Atoll (Fig. 1). The 24 sites included lagoon and oceanic sites (Fig. 1). Each site offered an opportunity to document and to add to the typology a number of habitats found between 30 meters and the surface. A habitat typically extends over few tens of meters, but can be restricted to small meter-scale patches, or being located at narrow edges, escarpments and fronts.

As traditionally used now in a remote sensing context, habitats were described using a hierarchy of geomorphological, benthic cover, architectural (coral growth forms and seascape rugosity) and taxonomic information for the dominant habitat-structuring species. Each habitat was described using a medium-scale approach (Clua et al., 2006), and by taking wide-angle and medium-angle photography for archiving. Each different combination of variables found in the field provided a new habitat for the typology.

To complement the description of the habitats found in 23 sites, we also used the results from Le Berre et al. (2009) acquired for the AEC project. This extensive work provided coral cover and dominant growth forms around each Baa Atoll reef, thus covering the entire atoll with at least one observation for each section of reef, across the entire range of degrees of exposure. Le Berre et al. (2009) data were acquired in June 2008 by towing a snorkeler at the surface and in shallow waters (<10 meters deep) close to the reef. Photo transects (five pictures per transect) were conducted at the beginning and end of each of the 505 tows. The average tow length was 1.25 km. Photo transects were processed with the Coral Point Count with Excel extension (CPCe) software. Quantitative estimates of cover were obtained using 25 points per photo. Growth forms categories included: massive, tabular, branching, foliose, encrusting, digitate and submassive.

Remote Sensing and Map Data

To help planning the survey, and for subsequent conservation planning analyses, we used first a map from the Millennium Coral Reef Mapping Project (Andréfouët et al., 2006). The Millennium map of Baa was obtained from two Landsat images at 30 meter-resolution, from path-row 145-56 (acquired in 2000) and 145-57 (acquired in 2001). The classes mapped are geomorphological. They describe the main reef types and their geomorphological units, following a globally-valid protocol and classification scheme. Fifteen classes were needed to map Baa Atoll (Fig. 2).

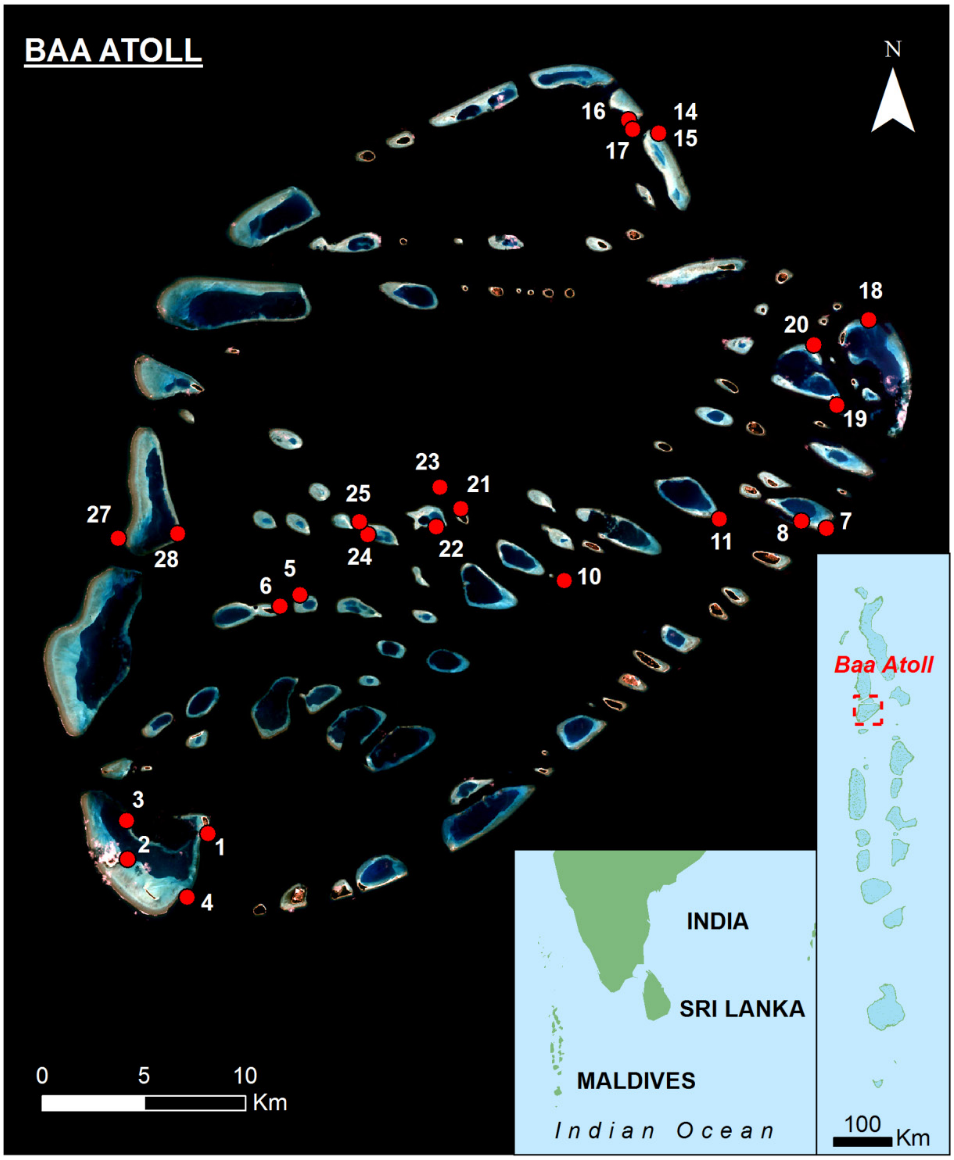

Figure 1. Map of Baa Atoll and position of the 24 habitat sampling sites visited in June 2009.

In 2010, the Department of Planning of the government of Maldives and the Marine Research Center provided a complete coverage of recent Quickbird images at 2.4 meter resolution. To cover the atoll entirely, different overlapping images acquired at different dates were needed. This resulted in a mosaic of heterogeneous quality due to different sea surface roughness and cloud covers. Each individual reef was thus processed independently, by taking advantage of the best coverage available. For the mapping, images were resampled at 5 meter resolution. No atmospheric correction nor water column correction was performed since most of the mapping was done by manual digitization, following the principles described in Andréfouët (2008). Sea surface correction was applied when needed, using the method by Hochberg et al. (2003).

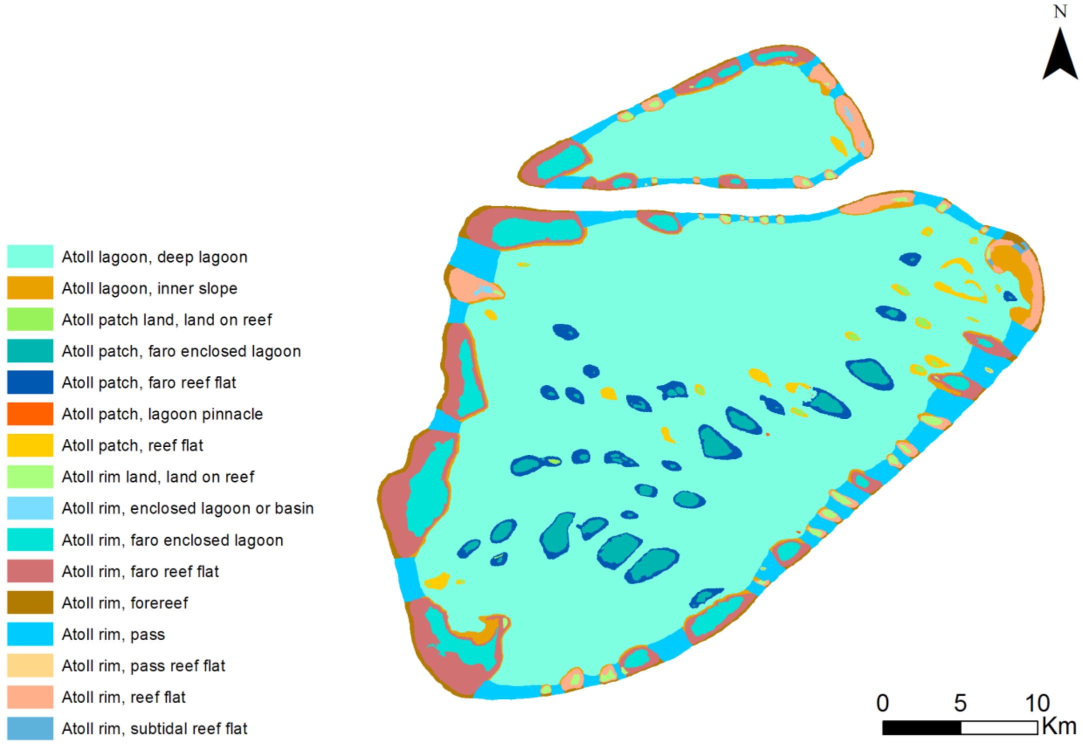

Figure 2. Millennium geomorphological map of Baa Atoll.

Principles for Mapping Baa Atoll for a Conservation Planning Application

The habitat mapping of Baa Atoll was conducted using the following principles: First, the data from Le Berre et al. (2009) covered the entire atoll, providing coral cover and dominant growth forms for each of the polygons corresponding to the upper forereefs of each mapped reef. Thus, we virtually eliminated omission errors (i.e., all habitats are represented at least once, where they were seen), but not necessarily commission errors for forereef habitats. This was acceptable given the final objective of the mapping, which is to use diversity of habitats for conservation planning (1km^2 management units). With this criterion, it was important to include in the mapping all the habitats observed at least once in the field, even if the spatial generalization was uncertain. Since Le Berre et al. (2009) provided a very dense array of observations, we could be certain that forereef habitat diversity would be correctly represented in the habitat map using this process.

Second, in other areas where ground-truthing was limited (in particular on reef flats), we limited the mapping at the hierarchical level of the habitat typology where uncertainties were minimized. Thus, if field data and images could not provide unambiguous clues on benthic coverage and architecture, we limited the habitat description to a detailed geomorphological description, higher in the hierarchy, and with a greater degree of certainty. Typically, branching communities on sandy bottoms and seagrasses coud be discriminated, but this was not necessarily the case for all the different coral assemblages found on hard-bottoms. Deep mesophotic lagoon areas, which were not sampled and described by Le Berre et al. (2009) remained mapped as "Deep lagoon".

Using the two principles above led to a low error map. However, different polygons may be labelled at different levels in the hierarchical habitat typology. Each habitat, either fully resolved or partially resolved throughout the hierarchy, was assigned a consistent weighting when deriving maps of habitat richness. This is a limitation that we acknowledge, as a generic "faro reef flat" will likely include more benthic and architectural variation than a "seagrass bed dominated by *Thalassia hemprichi, on faro reef flat*"

RESULTS

Qualitative General Field Observations

All the observations on the 24 sites confirmed the observations reported by Le Berre et al. (2009). The Figure 3 illustrates some of the habitats found in Baa.

Between 0-25 meters depth, the benthic and architectural complexity was low compared to other high island sites but comparable to atolls elsewhere in the world. The absence of fleshy algae-dominated habitats was noteworthy, as were limited seagrass habitats and the high occurrences of habitats dominated by coralline encrusting algae over remnants of coral formation, probably killed by the 1998 bleaching events. Eroded formations and breakages were frequent in lagoonal reefs, resulting in accumulation of loose substrate, or or substrate undergoing a process of cementation. Outer reef flats (crests) of the eastern outer rim (western outer rim reef flats were not visited) were mostly covered by small boulders exhibiting sharp transition towards pavement or sand habitats. Coral dominated habitats occurred on central lagoonal patch reefs (dominated by *Acropora* spp formations), and north-east oceanic slopes (*Porites* spp dominated formations). Mixed benthic assemblages were also found on the lower part of the lagoonal forereefs, and lagoonal reef flat tops. Sand and sediment plains dominated the 25-50 meters zone. In passes and pinnacles, high current zones, medium-high topography, overhangs, and small caves combined to provide habitats rich in fauna that frequently correspond to commercial dive sites. Low relief spur and grooves systems were dominated by pavement on the southern and western sides of the atoll. They appeared colonized by coral colonies of homogeneous sizes (communities of *Acropora* or *Pocillopora*), suggesting a recruitment episode 5-6 years ago.

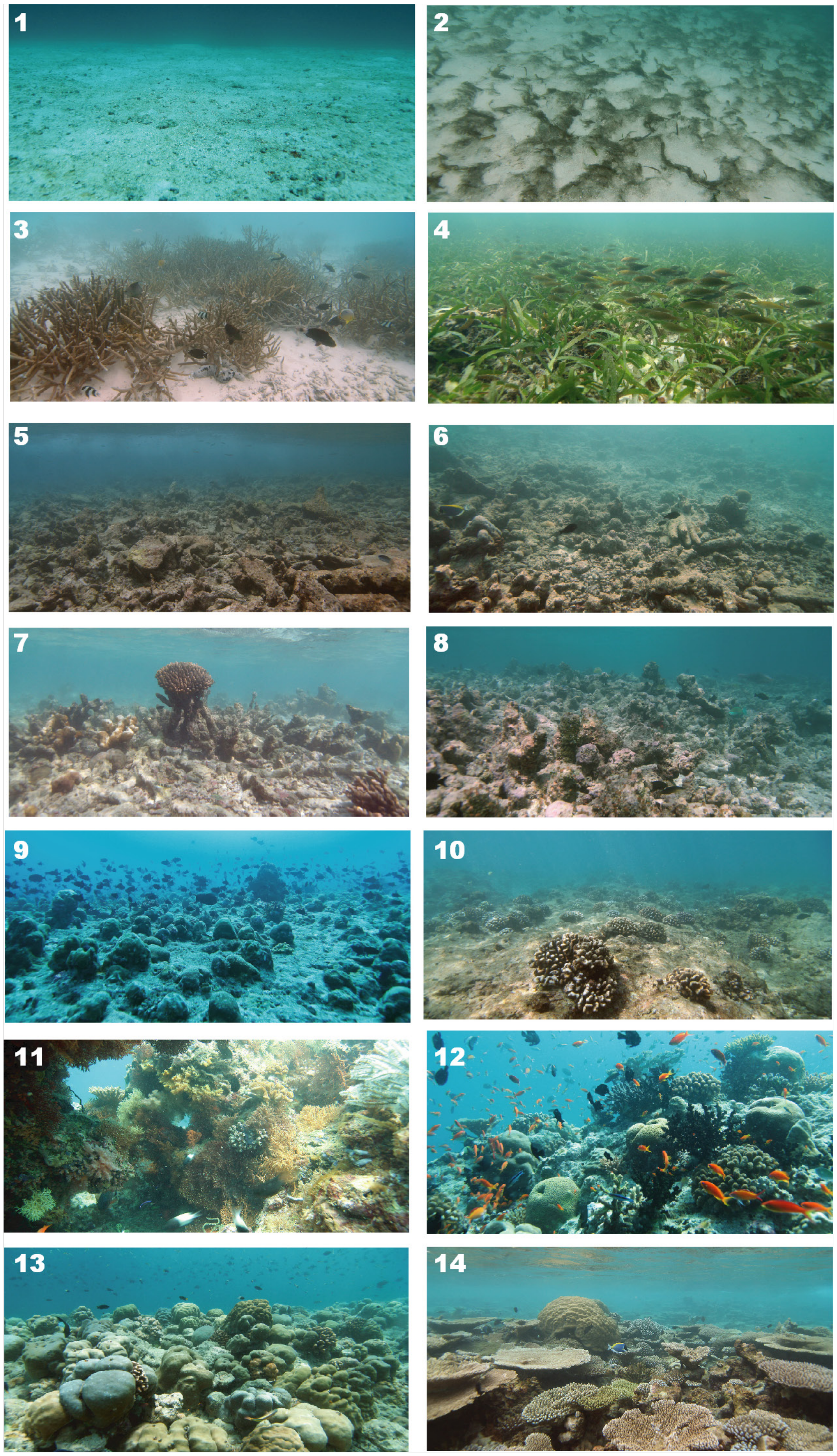

Figure 3. Examples of reef habitat found in Baa Atoll. From soft-bottom habitats (1-4) to boulder (5) to rubbles (6) to eroded coral substrates (7-8) to pavement with scattered corals of homogeneous sizes (9-10) to rugose and high current areas pinnacles and passes (11-12) to live massive or tabular coral dominated communities on reef tops (13-14).

Habitat Typology

Details of the habitat hierarchical typology are provided in Table 1 (geomorphology) and Table 2 (benthic cover and architecture). This typology was used to map habitats using the Quickbird images.

The geomorphology description (Table 1) is a three-level hierarchy, in agreement with the Millennium typology, but also with a few additional classes. The atoll is made of three Level 1 main structures (rim, patch reefs, and the lagoon) which themselves can be decomposed in a variety of geomorphological units at Level 2. Level 2 units can themselves be decomposed further in some cases. A label "*with constructions*" means that the image revealed numerous small coral constructions that were not individually mapped. They are aggregated and labeled as "*with constructions*". There were a total of 41 combinations, thus 41 classes. The islands described in detail by Kench (this issue) correspond to codes 10 and 27, respectively sitting on the rim and on central patch reefs.

Table 1. Geomorphological descriptors of the habitat typology. The column ID-G refer to the 1st and 2nd digit of the codes assigned to mapped polygons (see Fig. 4).

GEOMORPHOLOGY

ID-G	Geomorphology_L1	Code-GL1	Geomorphology_L2	Code_GL2	Geomorphology_L3	Code_GL3
10	Rim	1	Land	1	NA	0
11	Rim	1	Faro Enclosed Lagoon	2	Lagoon	1
12	Rim	1	Faro Enclosed Lagoon	2	Patch reef	2
47	Rim	1	Faro Enclosed Lagoon	2	Lagoon W/constructions	2
13	Rim	1	Faro Reef Flat	3	NA	0
14	Rim	1	Reef Flat	4	NA	0
15	Rim	1	Outer Forereef	5	NA	0
16	Rim	1	Inner Forereef	6	NA	0
17	Rim	1	Terrace	7	NA	0
18	Rim	1	Terrace w/constructions	8	NA	0
19	Rim	1	Deep Terrace	9	NA	0
20	Rim	1	Deep Terrace w/constructions	10	NA	0
21	Rim	1	Pass	11	NA	0
22	Rim	1	Pass Reef Flat	12	NA	0
23	Rim	1	Channel	13	NA	0
24	Rim	1	Subtidal Reef Flat	14	NA	0
25	Rim	1	Inner Reef Flat	15	NA	0
26	Rim	1	Pinacle	16	NA	0
49	Rim	1	Drowned reef	18	N/A	0
27	Patch Reef	2	Land	1	NA	0
28	Patch Reef	2	Faro Enclosed Lagoon	2	Lagoon	1
29	Patch Reef	2	Faro Enclosed Lagoon	2	Patch reef	2
48	Patch Reef	2	Faro Enclosed Lagoon	2	Lagoon W/constructions	2
30	Patch Reef	2	Faro Reef Flat	3	NA	0
31	Patch Reef	2	Reef Flat	4	NA	0
32	Patch Reef	2	Outer Forereef	5	NA	0
33	Patch Reef	2	Inner Forereef	6	NA	0
34	Patch Reef	2	Terrace	7	NA	0
35	Patch Reef	2	Terrace w/constructions	8	NA	0
36	Patch Reef	2	Deep Terrace	9	NA	0
37	Patch Reef	2	Deep Terrace w/constructions	10	NA	0
38	Patch Reef	2	Channel	13	NA	0
39	Patch Reef	2	Subtidal Reef Flat	14	NA	0
40	Patch Reef	2	Inner Reef Flat	15	NA	0
41	Patch Reef	2	Pinacle	16	NA	0
43	Lagoon	3	Terrace	7	NA	0
44	Lagoon	3	Terrace w/constructions	8	NA	0
45	Lagoon	3	Deep Terrace	9	NA	0
46	Lagoon	3	Deep Terrace w/constructions	10	NA	0
42	Lagoon	3	Deep Lagoon	17	NA	0
50	Lagoon	3	Pass	19	NA	0

Table 2. Benthic and architectural descriptors of the habitat typology. The column ID-B refer to the 3rd and 4th digit of the codes assigned to the mapped polygons (see Fig. 4).

Benthic cover and architecture

ID-B	Live Coral Cover (%)	Code_LCC	Benthic Community/Growth Form	Code_BCGF
50	0 - 5	1	Massive > 50%	1
51	0 - 5	1	Tabular > 50%	2
52	0 - 5	1	Encrusting > 50%	3
53	0 - 5	1	Digitate > 50%	4
54	0 - 5	1	Mix	5
55	0 - 5	1	Branching > 50%	6
56	0 - 5	1	Sub-Massive > 50%	7
57	0 - 5	1	Seagrass	8
58	5 - 10	2	Massive > 50%	1
59	5 - 10	2	Tabular > 50%	2
60	5 - 10	2	Encrusting > 50%	3
61	5 - 10	2	Digitate > 50%	4
62	5 - 10	2	Mix	5
63	5 - 10	2	Branching > 50%	6
64	5 - 10	2	Sub-Massive > 50%	7
65	10 - 15	3	Massive > 50%	1
66	10 - 15	3	Tabular > 50%	2
67	10 - 15	3	Encrusting > 50%	3
68	10 - 15	3	Digitate > 50%	4
69	10 - 15	3	Mix	5
70	10 - 15	3	Branching > 50%	6
71	10 - 15	3	Sub-Massive > 50%	7
72	15 - 25	4	Massive > 50%	1
73	15 - 25	4	Tabular > 50%	2
74	15 - 25	4	Encrusting > 50%	3
75	15 - 25	4	Digitate > 50%	4
76	15 - 25	4	Mix	5
77	15 - 25	4	Branching > 50%	6
78	15 - 25	4	Sub-Massive > 50%	7
79	25 - 40	5	Massive > 50%	1
80	25 - 40	5	Tabular > 50%	2
81	25 - 40	5	Encrusting > 50%	3
82	25 - 40	5	Digitate > 50%	4
83	25 - 40	5	Mix	5
84	25 - 40	5	Branching > 50%	6
85	25 - 40	5	Sub-Massive > 50%	7
86	> 40	6	Massive > 50%	1
87	> 40	6	Tabular > 50%	2
88	> 40	6	Encrusting > 50%	3
89	> 40	6	Digitate > 50%	4
90	> 40	6	Mix	5
91	> 40	6	Branching > 50%	6
92	> 40	6	Sub-Massive > 50%	7

Benthic descriptors used for the mapping included live coral cover (percentage) and dominant growth forms used principally to detail coral communities on both hard and soft substrates (Table 2 below). Distinctions between hard and soft substrates are not themselves part of the benthic description in contrast with usual practice for mapping. Indeed, since they appear implicitly related to the geomorphological units (Table 1), we avoided unnecessary redundancy by omitting explicitly this distinction at this benthic level. Combining the possible ranges of coral cover and growth forms generated a total of 43 benthic combinations, thus 43 classes. Seagrass beds characterized one benthic class with low coral cover.

Quickbird-derived Habitat Map

Habitat mapping was done by labeling each digitized polygon with a mandatory geomorphological code. When certain, a benthic code was concatenated to the geomorphology code. This was systematically done for foreeefs following the observations reported by Le Berre et al. (2009). The achieved Quickbird derived habitat product is shown Figure 4.

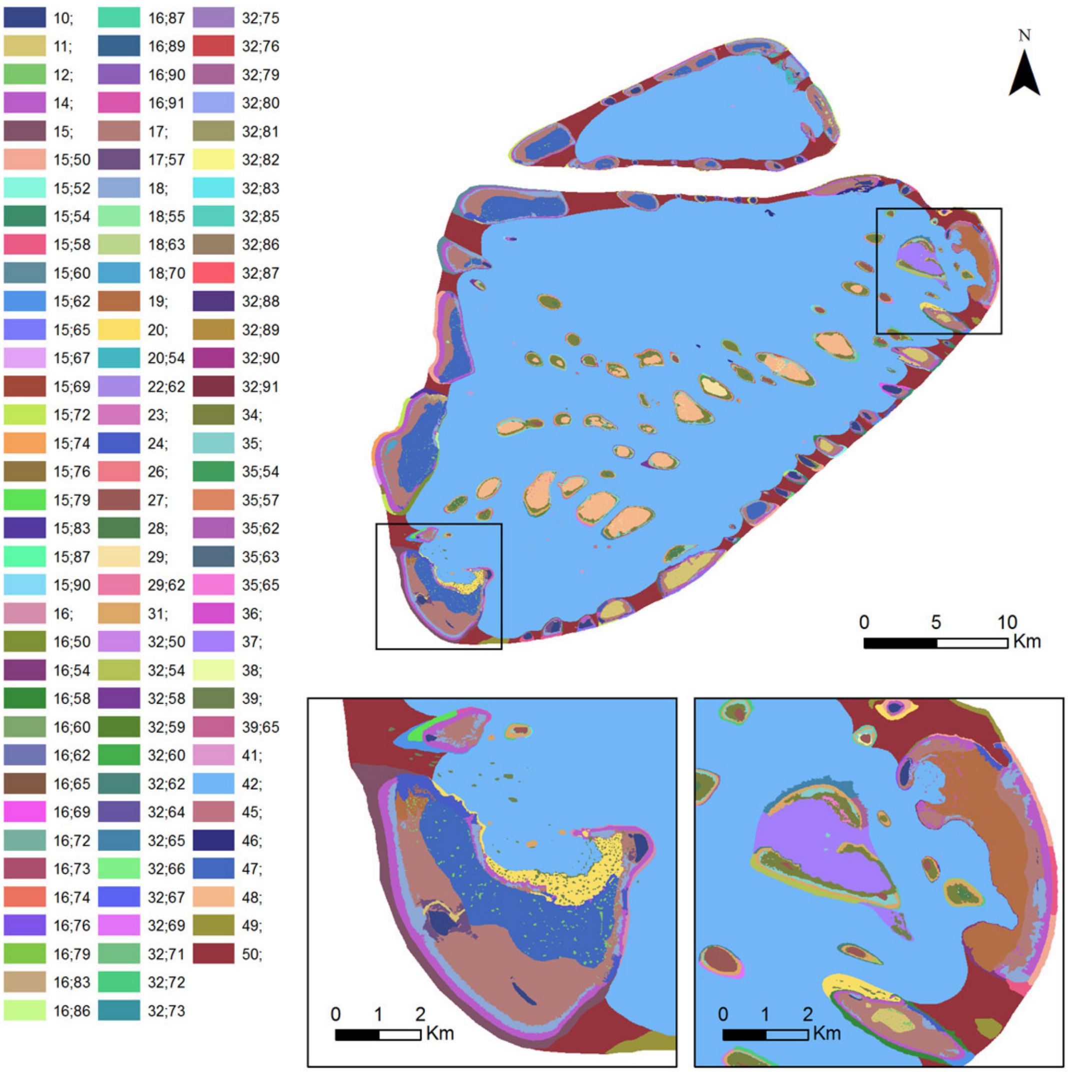

Figure 4. Illustration of the Quickbird-derived habitat maps. Each color corresponds to a different habitat. Two enlargements are shown for structurally complex areas, with numerous patch reefs. The two first digits of the codes refer to geomorphology (cf. Table 1, ID-G). With 4-digit codes, the two last digits refer to benthic description (cf. Table 2, ID-B)

Considering the full hierarchy, the complexity of the product reaches 106 habitat classes (Fig. 4). This is a very high number of classes, but in agreement with the level of detail that can be achieved following Andréfouët (2008)'s user oriented scheme. The input provided by Le Berre et al. (2009) data significantly increased the complexity, compared to what could be typically done without similar amount of field data (e.g., 56 classes in Wallis Island, a high island with fringing, patch and barrier reefs, Andréfouët, 2008).

The 106-class map highlights what is technically possible to achieve. However, managers and other users may not want to systematically consider such a high number of classes for their application. Obviously, few tens of classes represent a more manageable number, which may be more relevant for a given application (Gilbert et al. 2006). There is indeed a threshold in class numbers, above which plotting maps on screen and in print becomes confusing (Figure 4 illustrates the complexity of spatial patterns, but the color coding may not be optimal in print). The hierarchical attributes allow representing different information, geomorphologic (Fig. 5) and benthic (Fig. 6) depending on the needs, at a more traditional level of complexity.

DISCUSSION

Baa Atoll detailed habitat map was created following, for a large part, a standard mapping methodology (Andréfouët, 2008), but also following an unusual labeling procedure. Indeed, such labeling was only made possible with Le Berre et al. (2009) rapid survey dataset on coral cover and coral growth form. This dataset, exhaustive for the entire atoll, avoided the traditional accuracy assessment stage that should follow any mapping exercise to quantify the uncertainty and errors rates, and more importantly to provide confidence in the accuracy of the product. Here, confidence is brought by a map product constrained well enough by field data. Why? There are two reasons for that:

- First, for all forereef locations, there is at least one training ground-truth point for every polygon. This is luxury compared to most mapping projects. However, we acknowledge that variations may exist within each polygon, thus commission errors of unknown magnitude likely still exist.
- Second, the goal of the detailed Quickbird-derived map was to guide conservation choices. The goal was to identify areas of high habitat richness and define conservation area networks that would include occurrences of all habitats present in the atoll (Hamel and Andréfouët, this issue). Therefore, the required output was habitat richness, consistently estimated for each of the 1238 management unit (defined arbitrary as 1 km per 1 km cell by Hamel and Andréfouët, this issue). The mapping done here fulfilled this objective.

Below, we compare the different habitat richness products at 1 km resolution (Fig 7, 8 and 9). In Hamel and Andréfouët (this issue), we also compared the influence of the habitat map products for conservation scenario. Except Dalleau et al. (2010), to our knowledge, there are no other coral reef studies comparing the influence of maps with different thematic resolution for conservation planning. These comparisons help to define the relative benefits of using a detailed habitat map *vs* a coarse geomorphological map.

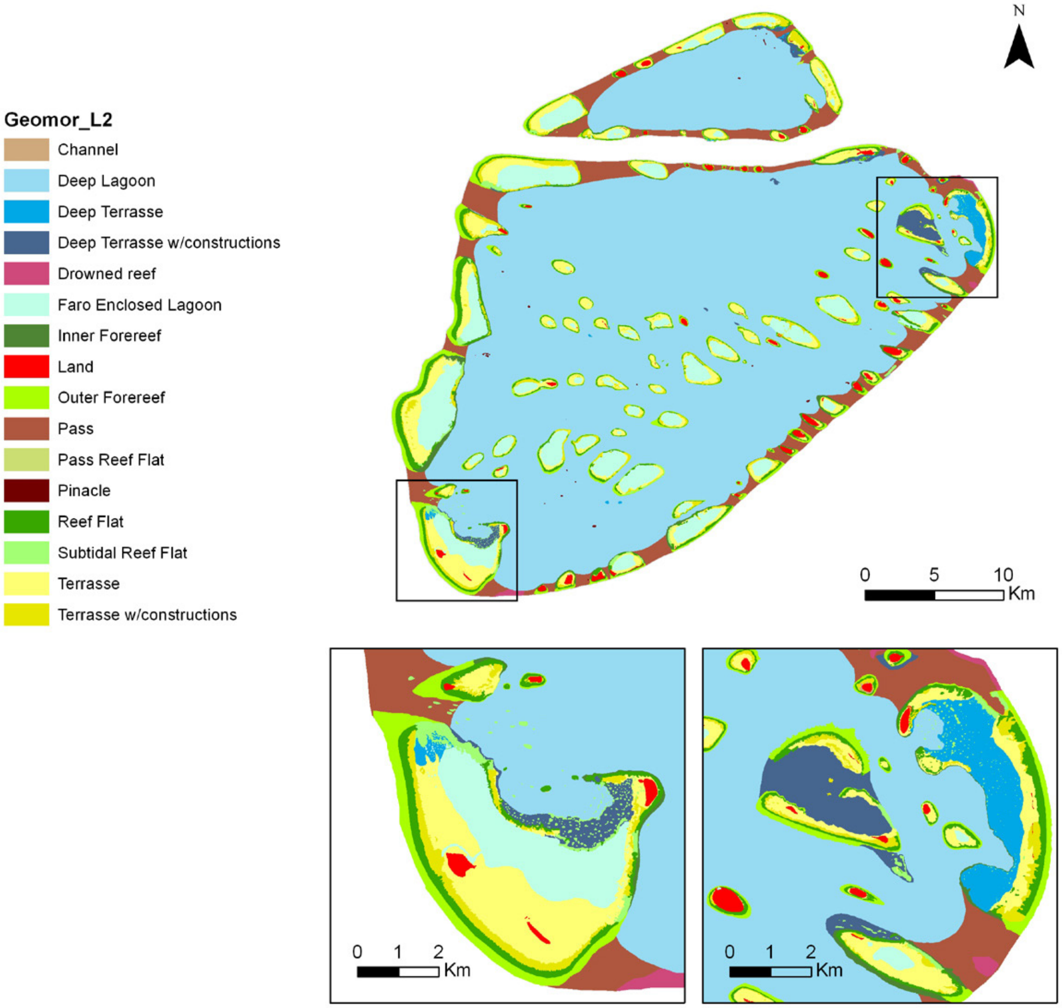

Figure 5. Illustration of the use of Quickbird-derived habitat maps. Each color corresponds to a different geomorphological class, at Level 2 (cf. Table 1, Geomorphology_L2). Two enlargements are shown for structurally complex areas, with numerous patch reefs.

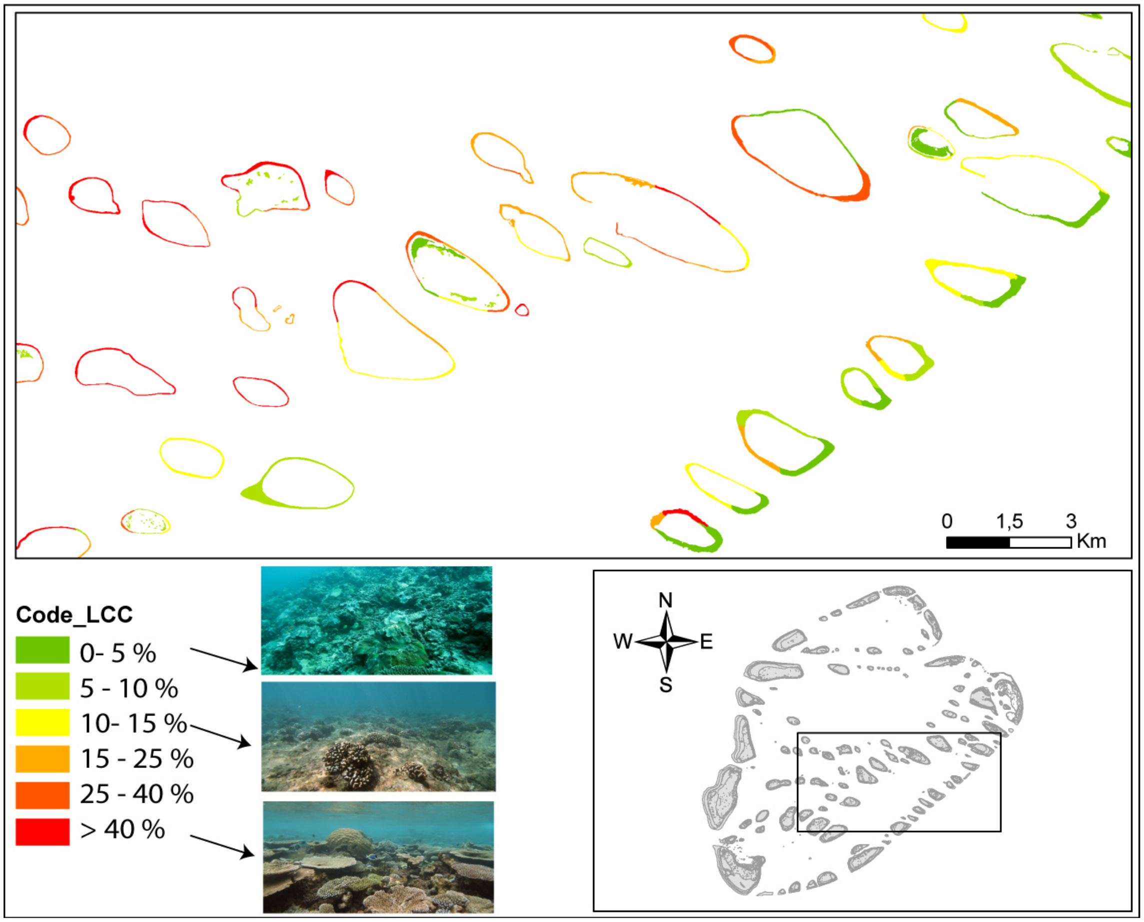

Figure 6. Illustration of the use of Quickbird-derived habitat maps. Each color corresponds to a different level of coral cover (cf. Table 2, Live Coral Cover %) Coral cover was assigned to forereefs, using Le Berre et al. (2009) data. Three examples of habitat illustrate coral cover levels. The map clearly shows the gradient from low coral cover on the oceanic forereefs to very high cover on the central patch reefs.

The relative patterns are consistent between the two products (Figs 7, 8 and 9), with higher diversity found along the atoll rim. However, in the Quickbird-derived habitat richness product, the central patch reefs are clearly more diverse than their LANDSAT counterpart. The figure 9 summarizes the differences. Also, given that the products are computed from respectively 15 and 106 classes, habitat rarity per grid cell is more frequent in the Quickbird product than in the LANDSAT one. Moreover, complementarity between sites is high. Thus, protected areas siting algorithms that use complementarity-rarity and complementarity-richness algorithms led to contrasted propositions of MPAs depending on which of the differing sensors were used (see Quickbird-derived MPA propositions in Hamel and Andréfouët, this issue). However, a caveat that we need to emphasize is that the computed richness as derived here is conservative. It is a minimum richness value. All polygons had the same weight in the richness analysis. It is possible that actual richness was higher on each mapped polygon than the value 1, due this time to intra-polygon omission errors (existing polygons could have been broken in more habitats if tow data from Le Berre et al. (2009) were at higher resolution). Furthermore, large polygons mapped only at geomorphological level likely include intrinsically more detailed habitats than polygons mapped with a geomorphology and benthos code.

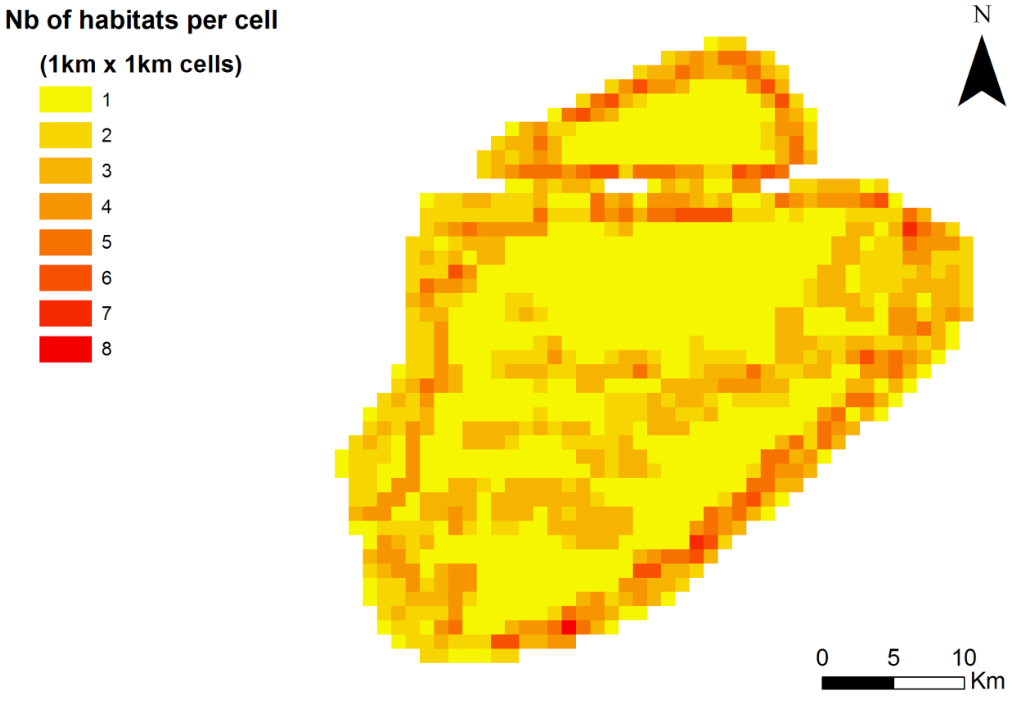

Figure 7: Geomorphological habitat richness (number of Millennium classes) for each cell of a 1 km grid overlaid on the Landsat derived habitat map.

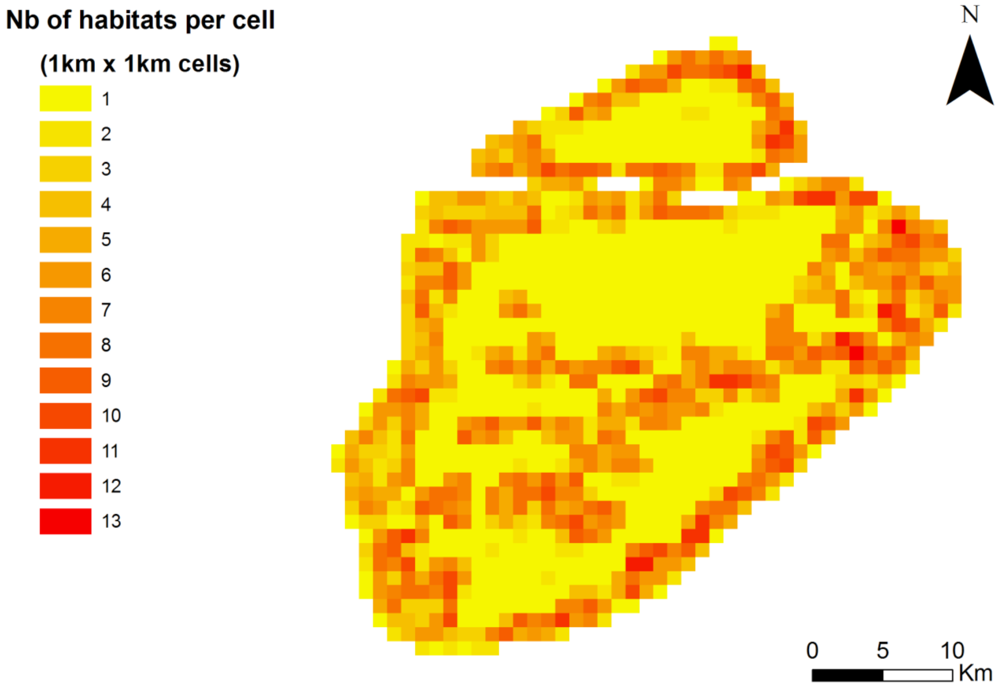

Figure 8: Habitat richness (number of habitats) for each cell of a 1 km grid overlaid on the Quickbird derived habitat map.

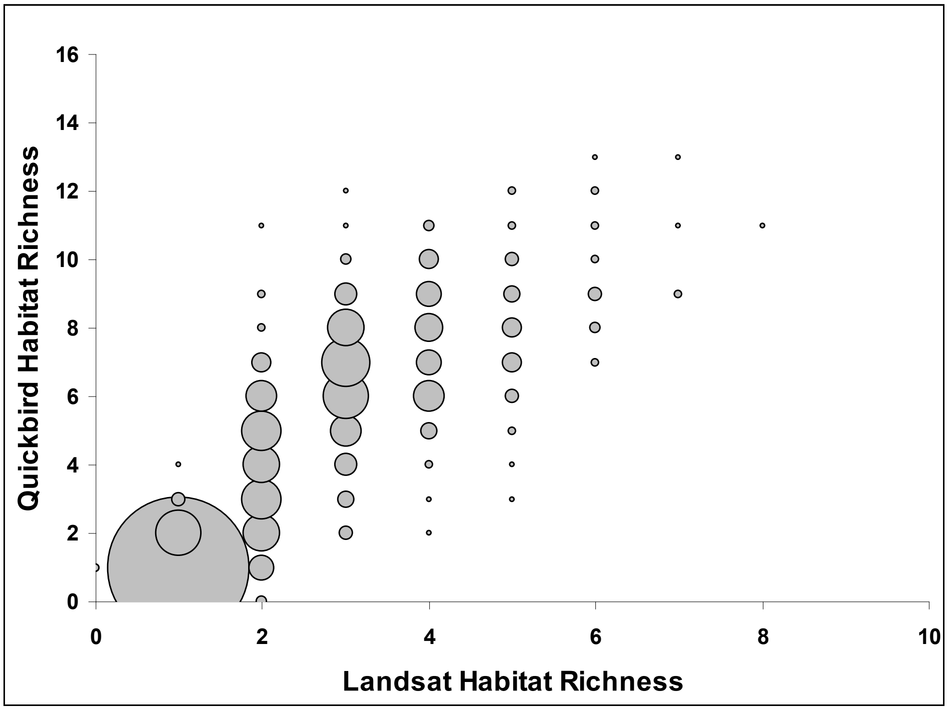

Figure 9: Comparison of Landsat-derived and Quickbird-derived habitat richness (number of habitats) for 1238 1-km^2 cells. The size of the bubbles is proportional to the number of cells with the given combination of richness. For instance, there are 501 cells with habitat richness equals to 1 for each sensor, in this case mostly found in the wide deep lagoon. Other bubbles represent between 1 and 64 co-occurrences.

CONCLUSION AND PERSPECTIVES

Geomorphology and benthic communities were mapped for the entire Baa Atoll using both LANDSAT and Quickbird satellite images. The mapping was conducted to serve conservation objectives (Hamel and Andréfouët, this issue).

To fill the gaps and continually improve the mapped product, further mapping work should now look in detail at polygons left mapped at coarse geomorphological level, especially those who are now included in protected areas or part of biodiversity and sea-level monitoring sites (Kench, this issue). The maps created here could also be immediately used to refine on-going monitoring programs with new sampling design based on an adaptive strategy, by combining spaceborne and field data (Scopélitis et al., 2010). There are still very few coral reef sites that benefit from detailed habitat maps at different thematic resolution, and on-going projects in Baa Atoll should take advantage of this in the future.s

ACKNOWLEDGEMENTS

The Quickbird images were made available by the Department of Planning of the Government of Maldives and by the Marine Research Center, thanks to Hussain Zahir and Shiham Adam. This study was funded by the French Fondation pour la Recherche sur la Biodiversité, Programme “Biodiversité des Iles de l’Océan Indien” and by the Atoll Ecosystem Conservation Project.

REFERENCES

Andréfouët, S., F. E. Muller-Karger, J. A. Robinson, C. J. Kranenburg, D. Torres-Pulliza, S. A. Spraggins, and B. Murch

2006. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. Pages 1732-1745. in Y. Suzuki, T. Nakamori, M. Hidaka, H. Kayanne, B. E. Casareto, K. Nadaoka, H. Yamano, M. Tsuchiya, and K. Yamazato, editors. *10th Int. Coral Reef Society. Japanese Coral Reef Society*, Okinawa, Japan.

Andréfouët, S.

2008. Coral reef habitat mapping using remote sensing: a user *vs* producer perspective. Implications for research, management and capacity building. *Journal of Spatial Science* 53:113-129.

Andréfouët, S.

2010. "Remote sensing" in Encyclopedia of modern coral reefs, structure, form and process. Ed. D. Hopley. Springer. pp. 920-930

Clua, E., P. Legendre, L. Vigliola, F. Magron, M. Kulbicki, S. Sarramegna, P. Labrosse, and R. Galzin

2006. Medium scale approach (MSA) for improved assessment of coral reef fish habitat. *Journal of Experimental Marine Biology and Ecology* 333:219-230.

Dalleau, M., S. Andréfouët, C.C.C. Wabnitz, C. Payri, L. Wantiez, M. Pichon, K. Friedman, L. Vigliola, and F. Benzoni

2010. Use of habitats as surrogates of biodiversity for efficient coral reef Conservation planning in Pacific Ocean Islands. *Conservation Biology* 24:541-552.

Gilbert, A., S. Andréfouët, L. Yan, and G. Remoissenet

2006. The giant clam Tridacna maxima communities of three French Polynesia islands: comparison of their population sizes and structures at early stages of their exploitation. *ICES Journal of Marine Science* 63:1573-1589.

Hamel, M.A., and S. Andréfouët

2010. Using very high resolution remote sensing for the management of coral reef fisheries: Review and perspectives. *Marine Pollution Bulletin* 60:1397-1405.

Hochberg, E. J., S. Andréfouët, and M. R. Tyler

2003. Sea surface correction of high spatial resolution Ikonos images to improve bottom mapping in near-shore environments. *IEEE Trans. Geociences and Remote Sensing* 41:1724-1729.

Le Berre, T., E. Emanuelli, E. Roussel, C. Guignard, A. Sivad, M. Saleem, and H. Zahir

2009. Rapid Marine Ecological Baseline Assessment of Islands of Baa atoll. *Technical report SEAMARC, Atoll Ecosystem Conservation Project,* 156 pp.

Purkis, S. J., N. A. J. Graham, and B. M. Riegl

2008. Predictability of reef fish diversity and abundance using remote sensing data in Diego Garcia (Chagos Archipelago). *Coral Reefs* 27:167-178.

Scopélitis, J., S. Andréfouët, S. Phinn, L. Arroyo, M. Dalleau, A. Cros, and P. Chabanet

2010. The next step in shallow coral reef monitoring: combining remote sensing and in situ approaches. *Marine Pollution Bulletin* 60:1956-1968.sur la Biodiversité, Programme "Biodiversité des Iles de l'Océan Indien" and by the Atoll Ecosystem Conservation Project.

BIODIVERSITY-BASED PROPOSITIONS OF CONSERVATION AREAS IN BAA ATOLL, REPUBLIC OF MALDIVES

BY

MÉLANIE A. HAMEL[1,2] AND SERGE ANDRÉFOUËT[1]

ABSTRACT

The Republic of Maldives is an atoll country entirely composed of coral reefs and is vulnerable to the many threats that may impair the resilience of coral reefs. Ongoing projects aim to enhance scientific knowledge of Maldives ecosystems and promote conservation. As a contribution to the Atoll Ecosystem Conservation project (AEC) focused on Baa Atoll, we identified high priority conservation areas using a unique biodiversity dataset (macrophytes, coral, fish, hydrozoans and other select macro-invertebrates census) and detailed habitat maps derived from Landsat and Quickbird satellite imagery. Species richness and distribution were mapped across the atoll and used by sitting algorithms to identify areas of high priority for biodiversity conservation. Algorithms were parameterized with the ConsNet software to meet species representation criteria within a conservation area network as compact as possible. These are conceptually simple classical designs, but they remain surprisingly seldom applied in coral reef conservation management. The design led in Baa to conservation choices likely to be accepted by Maldivian stakeholders. Indeed the recommendations are consistent with parallel AEC recommendations made according to charismatic mega-fauna distribution and tourism industry interests. The Baa Atoll example provides an illustrated step-by-step conservation planning procedure that can be easily replicated elsewhere.

INTRODUCTION

The Republic of Maldives consists entirely of coral reefs, the most diverse of all marine ecosystems. Maldives includes 26 geographical atolls, composed of approximately 1,190 individual coral structures (islands, *faro,* patches and knolls) (Hoon et al., 1997). The increasing local population is concentrated on only a few reef-islands and a growing number of resort-islands accommodate tourists in most atolls. In the past decades, coral reefs and marine biodiversity in general have driven economic incomes through fishing and tourism. Population growth and hotel construction increased both demand for sand and coral mining, and also levels of reef fishing (Sattar et al., this issue). Climate change is also a severe threat, mainly characterized by bleaching events such as in 1998 (Wilkinson et al., 1999), and sea level rise.

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The Maldivian government, recognizing the value of coral reefs for the tourism industry (Environment Protection and Preservation Act of Maldives 4/93), established 15 Marine Protected Areas (MPAs) in 1995, followed by 10 more in 1999. One more was implemented in 2007 and more recently, three MPAs were established in 2009. Today, the Maldives have 29 MPAs spread across 12 atolls, but most implementation decisions have been made on an *ad hoc* basis, principally driven by popularity as dive sites and without preliminary site characterization. Recently, the Government of Maldives together with the United Nations Development Program (UNDP) and Global Environment Facility (GEF) launched the Atoll Ecosystem Conservation Project (AEC) (www.biodiversity.mv/aec, (AEC, 2009b, a)). The purpose of this project is to design an effective management system for atoll ecosystem conservation and sustainable development (AEC, 2009a). Baa Atoll (also called *South Maalhosmadulu Atoll*) was the pilot atoll selected to conduct the AEC project. The atoll was recently recognized as a UNESCO Biosphere Reserve in 2011.

Part of the AEC task is also to establish new MPAs in Baa Atoll, based on clearly established conservation targets and supported by adequate data collection. AEC has conducted rapid surveys for this purpose (Le Berre et al., 2009) and designed a conservation plan focused on indicator species (e.g. megafauna like whale sharks, manta rays and sea turtles) and ecosystems.

Our project contributes to the AEC project by proposing alternative MPA solutions using a new biodiversity dataset specifically collected for this purpose. The biodiversity dataset includes species lists for macrophytes (Payri and Mattio, this issue), corals (Bigot and Hamir, this issue), fish (Chabanet et al., this issue), hydrozoans (Gravier-Bonnet and Bourmaud, this issue), other select macro-invertebrates (select classes of Cnidaria, Echinodermata, Mollusca, Porifera, Chordata, Plathelminthes, and Annelida, Andréfouet et al., this issue, a), and habitat maps (Andréfouët et al., this issue, b). These datasets allow inserting in a two dimensions spatially-explicit framework (the habitat maps), the multi-taxa points of biodiversity census.

We report here on the strategy followed to locate areas of high conservation priority using this biodiversity dataset, in order to meet species representation conservation criteria. The proposed networks of MPAs can be used by AEC and other stakeholders as a first objective basis for biodiversity conservation, and to feed more holistic conservation planning strategy based on criteria of different nature (e.g socio-economy, climate change or resilience).

METHODS

Study Area

Baa Atoll (Fig. 1) is the focus of the AEC project. It comprises 75 individual reef and *faro* for a total area of approximately 1200 km². Ten islands are inhabited, with a combined population of approximately 11000 people. Thus far, six islands have been developed as resorts and new projects are planned. While resorts have become the main economic driver, tuna and reef fishing remains an important activity on Baa Atoll (Sattar et al., this issue). Four MPAs have been implemented in the atoll since 1999.

Input Data to Design a MPA Network for the Conservation of Coral Reef Biodiversity

Biodiversity was characterized by establishing species lists for 31 study sites: 29 benthic/fish sites, and two additional plankton sites (for hydrozoans). Rationales for site selections and specific taxonomic work are detailed elsewhere for each taxon (Andréfouët and Adam, this issue). In short, sites were selected to represent: 1) the different geomorphological and exposure strata (e.g. oceanic forereef, lagoonal, patch reef, forereef, etc.); 2) a range of coral cover, abundance, and growth forms, (reported by the initial AEC rapid surveys (Le Berre et al., 2009)) and; 3) spatial coverage (north to south, east to west).

For species data, the goal of the sampling strategy was to obtain the taxonomic composition of five different groups of taxa (macrophytes, coral, fish, hydrozoans, and other select invertebrates) in the same locations, thus providing a comprehensive multi-taxa list consistent across all sites. Despite the possible limitations related to the identification of some groups, such a dataset is unique. Indeed, taxonomic inventories generally include less biological groups (for example, fish and corals only), or groups that are sampled at different stations throughout the targeted area (e.g. Dalleau et al., 2010). Among the 29 benthic and fish sites sampled in Baa (Fig. 1), we only used the 18 sites where all taxa were surveyed.

The various taxa inventories yielded 178 species of macrophytes, 173 species of coral, 350 species of fish, 115 species of hydrozoans, 182 species of other selected invertebrates, for a total of 998 species combined on all 29 sites. On the 18 sites with exhaustive inventories, 941 species were recorded.

For habitat data, we used two different maps produced from Landsat satellite images at a spatial resolution of 30m, and Quickbird satellite images at a spatial resolution of 2.4m. Methods used to produce these maps are detailed in Andréfouët, Rilwan, Hamel (this issue). The Landsat derived habitat map contains 16 classes of geomorphological habitats. The Quickbird-derived habitat map contains 106 classes of habitats defined by information on: 1) geomorphology; and 2) benthic communities and structure.

All habitats maps (obtained from Landsat and Quickbird imagery) and species inventories were included into a database and into a Geographic Information System (GIS) project. Seven of the 16 habitats (44%) present in the Landsat-derived habitat maps were sampled, and 12 of the 106 habitats (11%) present in the Quickbird-derived habitat map have been sampled.

Mapping Biodiversity

To create a map of biodiversity for the entire atoll, we combined the point biological census data with the habitat maps. A list of species per habitat was compiled. Each habitat received, as associated species, all the species that were found in this habitat,

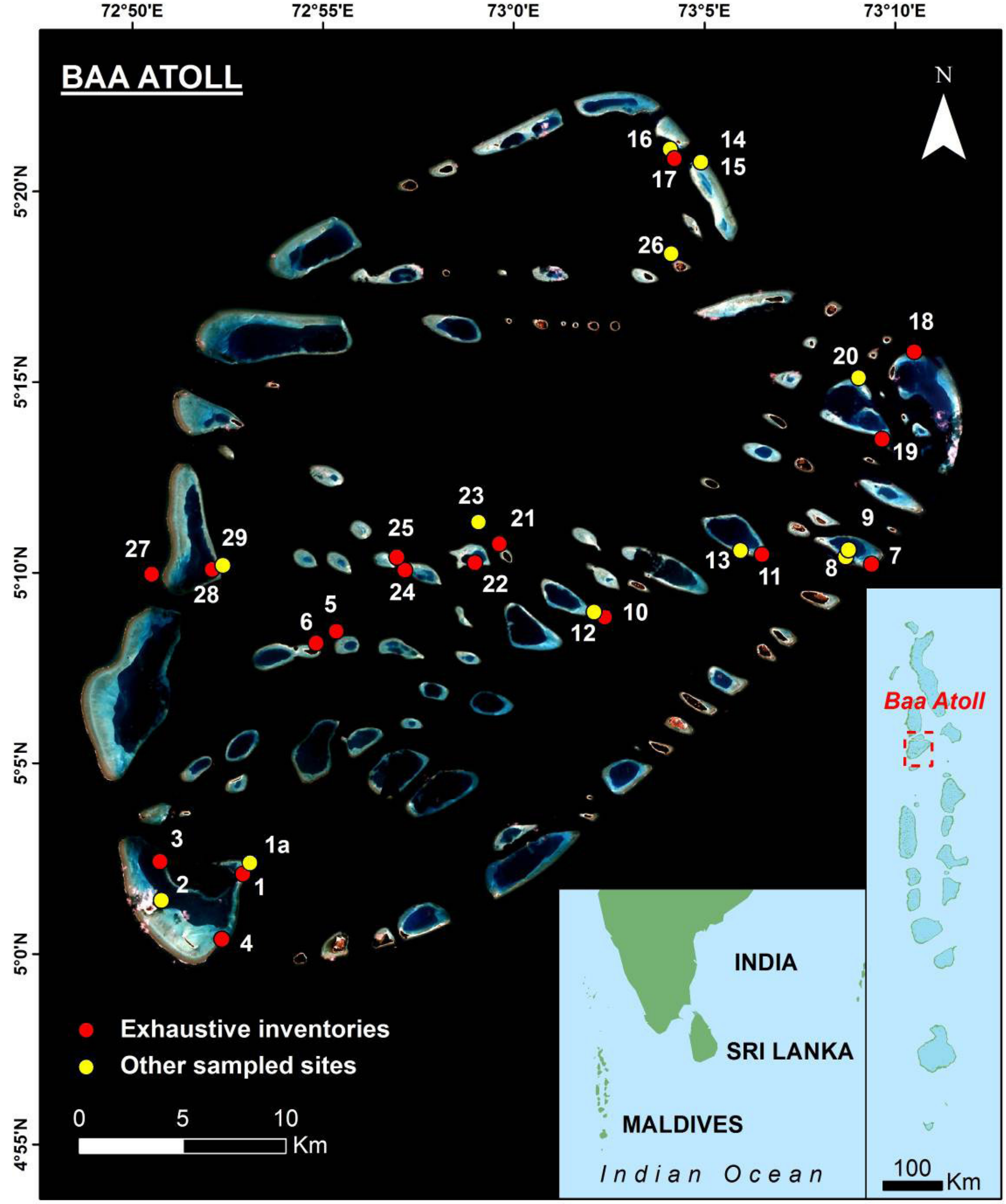

Figure 1. Location of Baa Atoll, Republic of Maldives in the Indian Ocean, and the sampling sites. Red circles correspond to the 18 sites where all taxa (macrophytes, coral, fish, hydrozoans and other select macro-invertebrates) have been inventoried. Yellow circles correspond to other sites that have been inventoried for only specific taxa, and thus for which a complete inventory is not available. Only fully surveyed sites have been used in the present study.

regardless of the location of the sampling site in the atoll. Baa Atoll was then partitioned into a grid of one by one kilometre cells covering the total mapped area. For each cell in both Landsat and Quickbird-derived habitat maps, we computed:

1) a list of the habitats present,
2) the habitat richness and,
3) a list of species per cell compiled from all habitats in the cell.

This three-step process is a straightforward way to generalize species distribution using habitat maps. We assumed that similar habitats in different atoll location would support similar assemblages of species, and thus similar amounts of biodiversity. This method is analogous to the process of creating species distribution or abundance maps from species records and mapped environmental predictors (e.g. via predictive models or geographic interpolation) (Jennings, 2000, Rodriguez et al., 2007, Choi et al., 2011). The difference in our method is that we used only one habitat map (either from Landsat or Quickbird imagery), itself the result of a variety of geological, environmental, ecological and climatic factors usually used to predict biodiversity patterns.

Selection of Conservation Units

To propose MPA locations, we used the gridded generalised map of biodiversity with the ConsNet software package (Ciarleglio et al., 2009). Our objective was to represent every single species at least a number of times *x* (representation target) in the proposed network while minimizing the number of selected cells. To assess sensitivity of the scenarios to the representation target, we chose to generate solutions for three different threshold of representation (*x*). In other words, if *x*=1, we sought at least one representation of each single species in the conservation network. We created scenarios for *x*=1, 5 and 10.

The use of heuristic solutions allows a fast exploration of the solution domain, and provides starting points for an exhaustive search. This strategy was adapted to our conservation objective because the ConsNet heuristics is constrained by the 'Minimum Area Problem', i.e. selecting the fewest cells possible meeting the representation target. The 'Minimum Area Problem' conservation constraint (or 'objective' in ConsNet) has several advantages: it is widely used and easy to understand and set up, it has an excellent ability to drive search, and it has no potential for failure (Ciarleglio et al., 2009).

Heuristic solutions were created with three different algorithms (for details, see Ciarleglio et al., 2009). In our case, for each algorithm, the surrogates of overall biodiversity correspond to the recorded species in all taxa.

1) The 'Most Deficient Surrogates' (MDS) complementarity algorithm adds cells to the network that reduce the most the remaining deficits. When all targets are met, the deficit is null.
2) The 'Rarity First' (RF) algorithm adds cells that contain the rarest species which have not yet met the representation target.
3) The 'InterLeaves' (ILV) algorithm adds cells with the rarest and most deficient species.

Extended search for best solutions also used the 'Minimum Area Problem'.

No constraint on the redundancy of cells in the network was requested. Importantly, no minimum area or maximum cost constraints have been implemented, in contrast to theoretical recommendation for conservation planning when resources are limited. Here, this was not necessary, as the goal is to propose MPA solutions based on biodiversity, without further clear specifications from AEC to use any cost function. Nevertheless, we chose to take into account the compactness of the network (i.e. we promoted the selection of few large MPAs instead of many small MPAs) to propose networks of MPAs that would be logistically easier to manage.

RESULTS

Distribution of Species Richness

On the 18 sites where there was a complete inventory of all taxa (Fig. 2), there were between 214 and 301 species per station, and an overall total of 941 species.

The generalisation of species distribution from Landsat-derived habitat maps provided 1199/1234 cells with species information (97%). The generalisation of species distribution from Quickbird-derived habitat maps provided 469/1219 cells with species information (38%) (Fig. 3). Such differences in the generalisation results were expected given the differences between each mapping product. The results of the generalisation process are driven by the habitat associated to the sampling station, as well the number of habitats contained in a cell.

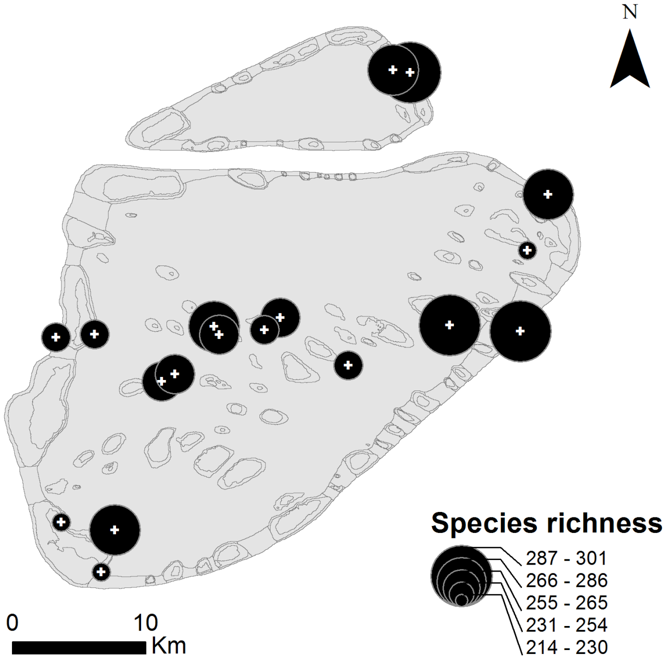

Figure 2. Variation of species richness for the 18 sampled sites where a comprehensive inventory of macrophytes, coral, fish, hydrozoans and other select invertebrates was available. Differences in species richness are small. Thus to ease visualization, species richness among sites is represented in five circle sizes, each corresponding to a class of richness (from 214 to 301 species) obtained with Jenks natural breaks classification method. The grey background map is the habitat map derived from Landsat imagery.

The most striking differences were for deep lagoon areas. With Landsat imagery, a number of small geomorphological units below 10 meter depth (pinnacles, etc.) could not be mapped and were thus part of the 'Deep Lagoon' class. Several census stations were thus included in the Deep Lagoon class, and the Deep Lagoon class were allocated the species from these stations. Conversely, with Quickbird, these small units could always be mapped individually, and assigned to other classes of habitats than 'Deep Lagoon'. Thus, the Quickbird derived habitat map offered no species information for a much larger deep area than the Landsat map (Fig. 3). When species richness could not be estimated, the cells remained void of species and were not included in the MPA planning process.

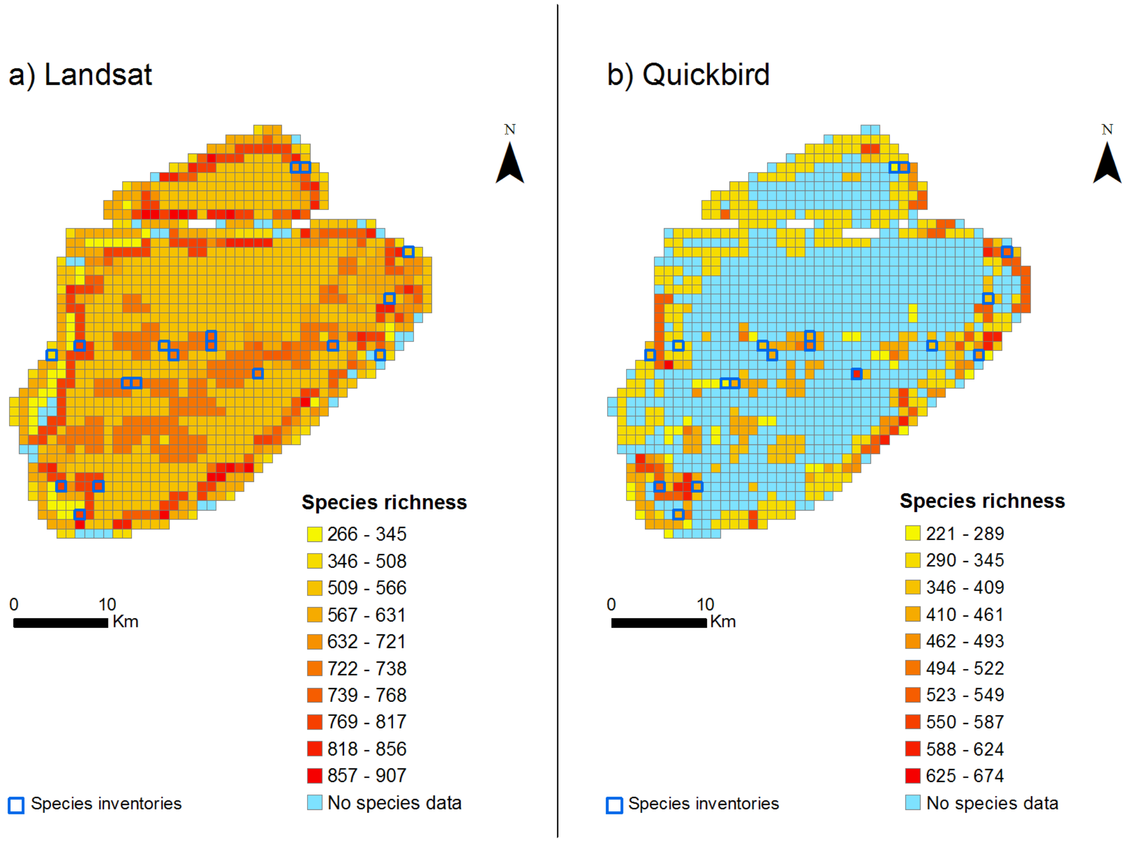

Figure 3. Spatial distribution of the estimated species richness for Baa Atoll (see text for details on the creation of these products). Blue cells remain virtually void of species because there is no species information for the habitats they contained, i.e. none of the sampled stations were located on those habitats. Cells with a dark blue border correspond to the conservation units which have been inventoried, i.e. cells we used as a basis for the generalisation procedure.

Identification of Conservation Areas Networks (CAN)

The ConsNet software returned several 'best' solutions for the planning of MPA networks in Baa Atoll that were quite different. The algorithm easily reached the conservation objectives, i.e. it reached the target for each species recorded, in the minimum number of cells possible. The examples shown in Fig. 4 are a sample of all possible designs for the same dataset and conservation objectives, but there are many other solutions.

As expected, the use of generalisations from Quickbird maps returned larger CANs than when using species richness maps from a Landsat habitat classification. If the objective was to represent every species at least once in the CAN, the algorithm proposed protection of two sites using the generalisation based on Landsat imagery, against six with the Quickbird generalisation. With a 10 species target, the use of the Landsat generalisation generated a 24-cell CAN, including two of the sampled sites. With the Quickbird map, 70 cells were selected, including five of the sampled sites.

DISCUSSION

The aim of this study was to provide AEC and Maldivian stakeholders involved in the conservation of Baa Atoll biodiversity with an objective layer to identify sites that deserve adequate conservation. We based our analyses and site selection on clear and quantitative biodiversity criteria.

Although this seems to be a fairly simple and straightforward process, despite an abundant literature on MPAs and conservation planning, there is surprisingly little other similar studies available for a coral reef environment, and none for atolls. Conservation planning tools have been used in 'the real world' (i.e., with the participation of local stakeholders and governmental agencies), for instance for the Great Barrier Reef in Australia (Fernandes et al., 2005) and for the coastal reef systems of Kimbe Bay in Papua New Guinea (Green et al., 2009). Atoll systems within the Phoenix Islands Protected Area in Kiribati have been recently declared protected areas and World Heritage Areas, but entire atolls were included, without spatial analysis. Biodiversity-driven conservation planning examples appear to remain limited. We expected that conservation planning driven by biological data would be frequent, but this is not the case. It may be that such studies remain technical and are not published in peer reviewed journals, but our experience in developing and developed countries suggest that there are likely no plethora of hidden gems. Ongoing planning often prioritizes socio-economic information, and biological information is often utilised as secondary decision-support layers.

The trend in the scientific literature is to propose increasingly complex theoretical schemes that account for processes that are poorly characterized worldwide, such as climate change effects, maintenance of reef resilience, meta-population connectivity and so forth. These remain only interesting theoretical exercises. They cannot be implemented in most places, and are of doubtful practical value in the real management world given the necessity of prompt action.

Conceptually and methodologically, the present study is straightforward. It provides simple guidelines that can be replicated elsewhere with adequate expertise (i.e., taxonomic knowledge, habitat mapping, and conservation planning software). It is a simplification of recommended theoretical conservation schemes, as neither socio-economic drivers nor important ecological processes (e.g., connectivity) are taken into account in our design. Given the lack of adequate knowledge of these processes, that will take years to be acquired, our immediate goal was to create a biodiversity-based recommendation layer. It has to be used in conjunction with other key constraints before

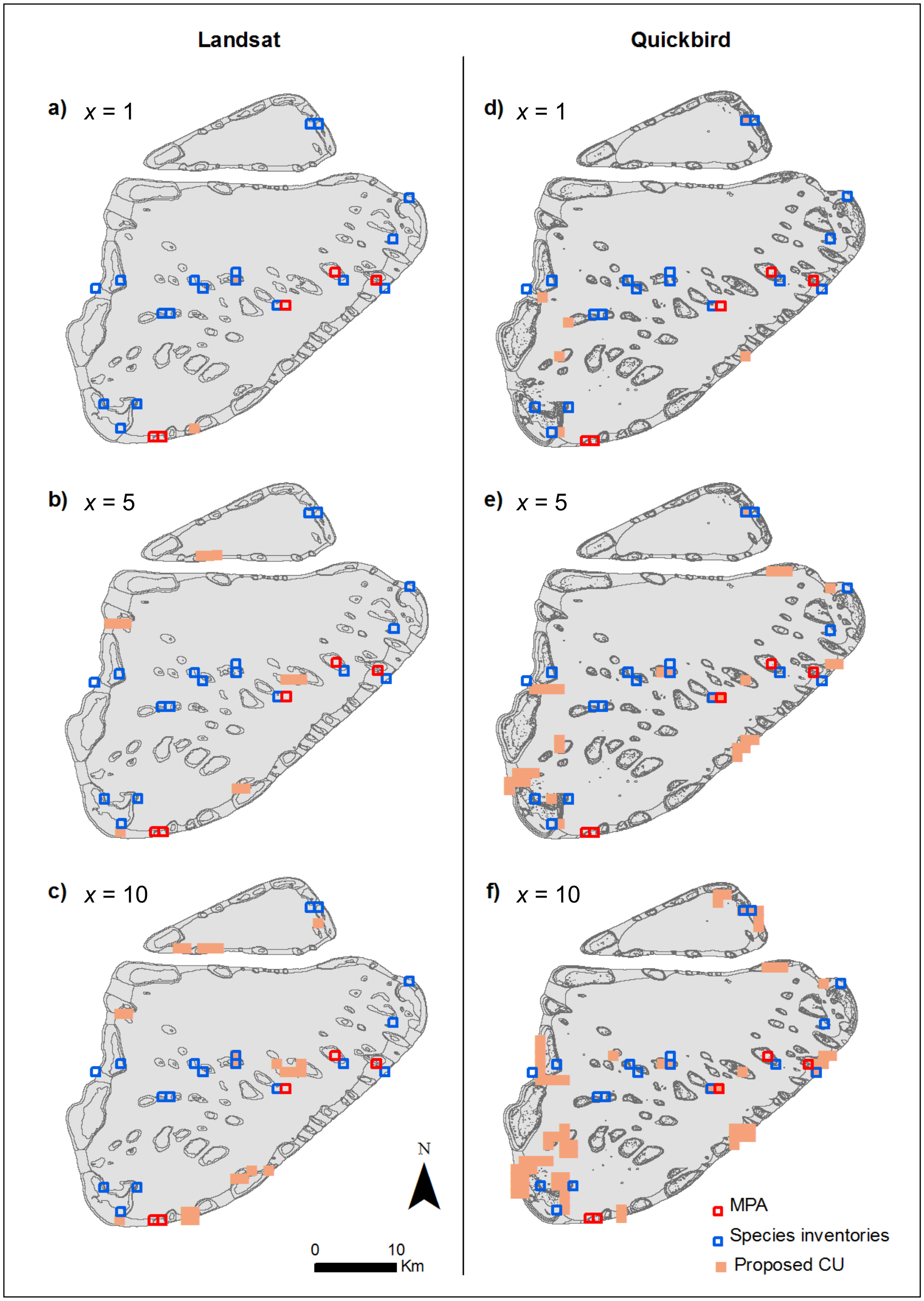

Figure 4. Proposed Conservation Units (CU) in Baa Atoll obtained with the ConsNet software from the generalised maps of species richness. Each map is one example out of the many best solutions for MPAs networks generated by the software for the same conservation objectives. From top to bottom, objectives were to include in the network a) and d) all recorded species at least once; b) and e) all species at least five times; and c) and f) all species at least 10 times.

reaching a final decision. Final decisions regarding the proposed network of MPAs should eventually be made using the full range of knowledge available, especially socio-economic characteristics.

From the various solutions available, the MPA network that we recommend for further consideration is presented in Fig. 4, f (see Fig. 5 for a map combined with additional AEC data). We selected the output presented in Fig. 5 primarily because it encompasses current existing MPAs, and includes a number of sampling sites, thus minimizing the uncertainty that could arise from the generalisation of species distribution using habitats. Seven MPAs have been implemented on Baa Atoll since 1999. Dhigalhi Haa, a famous site for sighting marine megafauna, was declared protected in 1999; Olhugiri Island and its house reef were declared protected in 2006 for its unique vegetation and fertile soil; and Agafaru, a popular dive site, was declared protected in 2009 as was Hanifaru, a now famous feeding aggregation site for whale sharks and manta rays. Earlier this year, five more protected areas were declared in Baa Atoll, including the increase in boundaries of two existing protected areas, Hanifaru and Dhigali Haa. The three new protected areas created in 2011 are Bathalaa region, Maahuruvalhi faru, and Mendhoo region.

The proposed network includes portions of five of the seven existing MPAs (see proposed MPAs 1, 2, 5, 7, 8 and 14 in Fig. 5), two sea turtle nesting sites (MPAs 2 and 10) and the two unprotected bird nesting sites (MPAs 2 and 12). It also includes a number of popular dive spots. Several MPAs are close to resort islands, thus likely making them more attractive and of higher value for visitors due to nearby areas with recognized biodiversity value and protective status (Roberts et al., 2001). As a consequence, it is expected that the proposed network will be more easily accepted by AEC and local stakeholders, who already have been through a number of meetings, discussions and negotiations to select these sites. The fact that several sampling sites are included in the network also offers a strong baseline for future monitoring of species diversity. Additional sampling efforts could also quantify how much was missed in the initial surveys.

Inherent limitations to the approach we followed here are mainly related to the intrinsic limitations of the datasets related to species identification within each taxa and of each habitat map. The financial resources available for the project allowed for sampling 29 sites, 18 multi-taxa sites, and five major taxonomic groups to do in the course of the three weeks survey. Increased sampling efforts may likely change the output, especially if other taxa are included.

As Baa Atoll is an oceanic atoll, the diversity of habitats is low, compared to systems with a well defined land-outer reef gradients (e.g. Wallis Island in Dalleau et al., 2010). The small inherent habitat richness in an atoll, distributed fairly evenly throughout the atoll, added to the spatial scale we chose (one by one kilometre cells) does not lead to well defined spatial patterns. This explains why MPA solutions can spatially be quite different from one scenario to another.

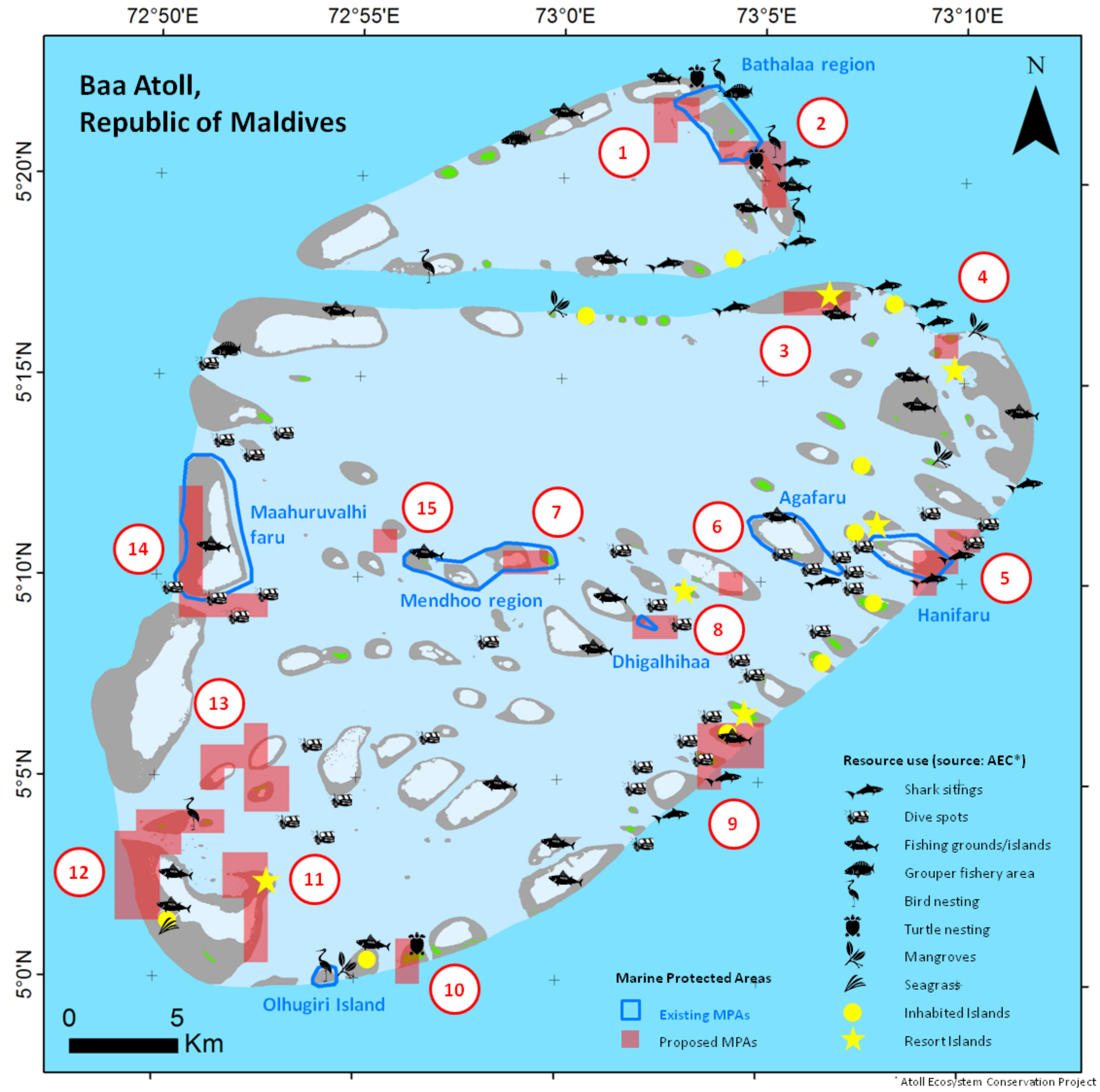

Figure 5. One of the proposed MPA networks (orange cells), overlapped with resource use information (black and yellow pictograms) extracted from a map provided by the Atoll Ecosystem Conservation Project (available to download at http://www.biodiversity.mv). Each number corresponds to a MPA contained in the network. In this case, the conservation objectives were defined to represent every recorded species at least 10 times in all combined conservation units (CU), within the smallest number of CUs, and taking account of the compactness of the network. The input species data were extracted from the generalised species map, obtained with a habitat map from Quickbird imagery and with the comprehensive biological inventories.

CONCLUSION

The conservation area networks proposed here offer to the Atoll Ecosystem Conservation project an objective basis to implement conservation decisions. The proposed network was built using a spatially-explicit consistent dataset, which allowed mapping of Baa coral reef biodiversity. This effort complements the previous AEC rapid assessment, that provided substantial information on other aspects of Baa unique environment such as mega-fauna or coral cover. The CAN shown in Fig. 5 is thus one of the many necessary milestones in a dynamic process aiming for long term conservation of Baa Atoll. Real world conservation network implementation is a long-term process requiring a wide range of data types and clear objectives to be able to move forward. This study brought a necessary biodiversity dataset to contribute to the process. We suggest that similar studies need to be conducted elsewhere to initiate the conservation planning process, especially when the biological system is poorly known. Even if ultimate recommendations and decisions may need to be based on socio-economic drivers and criteria, there is no doubt that the availability of such a biodiversity-based plan for conservation legitimates the process of decision making.

ACKNOWLEDGEMENTS

This study was funded by the French Fondation pour la Recherche Sur la Biodiversité, Programme "Biodiversité des Iles de l'Océan Indien" and by the Atoll Ecosystem Conservation project. We thank all the contributors to the various biological and mapping data sets.

REFERENCES

AEC
2009a. *Atoll Ecosystem Conservation Project: our vision & implementation strategy*. Atoll Ecosystem Conservation Project 2009.
2009b. *Baa Atoll Conservation Programme: 5 year Strategy / 2009 - 2013*. Atoll Ecosystem Conservation Project, Ministry of Environment Energy and Water, Government of Maldives, UNDP-GEF.

Choi, J.-K., H.-J. Oh, B.J. Koo, S. Lee, and J.-H. Ryu
2011. Macrobenthos habitat mapping in a tidal flat using remotely sensed data and a GIS-based probabilistic model. *Marine Pollution Bulletin* 62(3):564-572.

Ciarleglio, M., J.W. Barnes, and S. Sarkar
2009. ConsNet: new software for the selection of conservation area networks with spatial and multi-criteria analyses. *Ecography* 32(2):205-209.

Dalleau, M., A. Andrefouet, C. Wabnitz, C. Payri, L. Wantiez, M. Pichon, K. Friedman, L. Vigliola, and F. Benzoni
2010. Use of habitats as surrogates of biodiversity for efficient coral reef conservation planning in Pacific Ocean islands. *Conservation Biology* 24(2):541-552.

Fernandes, L., J. Day, A. Lewis, S. Slegers, B. Kerrigan, D. Breen, D. Cameron, B. Jago, J. Hall, D. Lowe, J. Innes, J. Tanzer, V. Chadwick, L. Thompson, K. Gorman, M. Simmons, B. Barnett, K. Sampson, G. De'ath, B. Mapstone, H. Marsh, H. Possingham, I. Ball, T. Ward, K. Dobbs, J. Aumend, D. Slater, and K. Stapleton

2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. *Conservation Biology* 19(1733-1744.

Green, A., S.E. Smith, G. Lipsett-Moore, C. Groves, N. Peterson, S. Sheppard, P. Lokani, R. Hamilton, J. Almany, J. Aitsi, and L. Bualia

2009. Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. *Oryx* 43(4):488-498.

Hoon, V., K.-C. Chong, R. Roy, B. Bierhuizen, and J.R. Kanvinde

1997. *Regional Workshop on the Conservation and Sustainable Management of Coral Reefs*. Project reports.

Jennings, M.D.

2000. Gap analysis: concepts, methods, and recent results. *Landscape Ecology* 15(1):5-20.

Le Berre, T., E. Emanuelli, E. Roussel, C. Guignard, A. Sivad, M. Saleem, and H. Zahir

2009. *Rapid marine ecological baseline assessment of islands of Baa Atoll.* Seamarc (Systems Engineering And Marine Consulting), La Mer Group.

Roberts, C.M., J.A. Bohnsack, F. Gell, J.P. Hawkins, and R. Goodridge

2001. Effects of marine reserves on adjacent fisheries. *Science* 294(5548):1920-1923.

Rodriguez, J.P., L. Brotons, J. Bustamante, and J. Seoane

2007. The application of predictive modelling of species distribution to biodiversity conservation. *Diversity and Distributions* 13(3):243-251.

Wilkinson, C., O. Linden, H. Cesar, G. Hodgson, J. Rubens, and A.E. Strong

1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change? *Ambio* 28(2):188-196.