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A new synthetic index to evaluate reef coral condition

Roberta Lasagna[a,b,*], Guido Gnone[a], Maura Taruffi[a], Carla Morri[b], Carlo Nike Bianchi[b], Valeriano Parravicini[c,d], Silvia Lavorano[a]

[a] Acquario di Genova, Ponte Spinola, 16128 Genoa, Italy
[b] DiSTAV, Department of Earth, Environment and Life Sciences, University of Genoa, Corso Europa 26, 16132 Genoa, Italy
[c] UR 227 CoReUs2, IRD (Institut de Recherche pour le Développement), Laboratoire Arago, BP 44, 66651 Banyuls-sur-mer, France
[d] CESAB-FRB, Immeuble Henri Poincaré, Domaine du Petit Arbois, Avenue Louis Philibert, 13857 Aix-en-Provence Cedex 3, France

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ABSTRACT

Coral reefs are threatened worldwide by climatic change and increasing anthropogenic pressures. Standardized and simple metrics assessing their status and their potential to recover are urgently needed to achieve large scale homogeneous information. Here we propose a synthetic Coral Condition Index (CCI) based on the proportional abundance of coral colonies belonging to six ordinal categories which represent their condition: recently dead, bleached, smothered, upturned, broken, and healthy. CCI ranges from 0 (100% of dead corals) to 1 (100% of healthy corals) with low values suggesting large scale disturbances (e.g., climate impacts), and high values suggesting disturbances acting on a small scale that can be averted by local management actions. We tested the performance of this index in Maldives, which suffered from coral mass mortality following bleaching in 1998 and mechanical damage due to the tsunami of 2004. In our evaluation CCI was applied on the most represented species, i.e., tabular *Acropora* and *Pocillopora*, which were counted from 2005 to 2010 using replicated belt transects at several depths and across different habitats. CCI did not show correlated to the number of total coral colonies suggesting the possibility to employ the index under different levels of coral abundance. CCI detected high levels of coral damage, which is likely due to the documented slow recovery of Maldivian reefs after the two major disturbance events. Further tests in other tropical regions with different coral species might promote CCI as an additional parameter for coral reef monitoring and restoration programs.

1. Introduction

Coral reefs are declining worldwide under the influence of multiple global and local disturbances of either natural or anthropogenic origin. Global warming has triggered extensive bleaching and mass mortality events across most tropical regions (Baker et al., 2008). Similarly, ocean acidification is hampering coral growth and survival (Kleypas and Yates, 2009). Natural disturbances range from storms and cyclones to crown-of-thorns starfish (*Acanthaster planci*) outbreaks, whereas anthropogenic impacts typically include tourism, fishing, anchoring, and pollution (Bryant et al., 1998). The complex interactions between natural and anthropogenic disturbances are resulting in what has been called the 'coral reef crisis' (Bellwood et al., 2004).

Distinction between natural and human-induced effects on marine ecosystems is often difficult and sometimes contentious (Brown, 1987; Nyström et al., 2000), but the synergy of all these factors has altered coral reefs in many localities of the tropical ocean (McClanahan, 2002; Hughes et al., 2003). Recent global analyses evidenced that about 75% of tropical reefs are severely threatened and 50% of them will be no more definable as such by 2050, producing concerns for the maintenance of ecosystem functioning and the associated flow of services that coral reefs provide (Wilkinson, 2008; Burke et al., 2011; Wilkinson and Brodie, 2011).

Coral reefs showed capable to persist during Quaternary climatic oscillations (Pandolfi and Jackson, 2006), but the recent increase in scale and frequency of disturbances has resulted in extensive 'phase shifts', i.e., changes in community structure and composition (Done, 1992; Montefalcone et al., 2011; but see Mumby et al., 2013), which make their potential to recovery unlikely (Knowlton, 2001; Dudgeon et al., 2010).

Halting downward trajectories of coral reefs and sustaining their resilience is therefore urgent and mandatory. While global impacts require international actions, regional management practices may help reducing local impacts (Knowlton and Jackson, 2008; Wooldridge et al., 2012). Targeted monitoring programs represent

* Corresponding author at: Acquario di Genova, Ponte Spinola, 16128 Genoa, Italy. Tel.: +39 010 2345 206.
E-mail addresses: robertalasagna@yahoo.it (R. Lasagna), ggnone@costaedutainment.it (G. Gnone), mtaruffi@costaedutainment.it (M. Taruffi), morric@dipteris.unige.it (C. Morri), nbianchi@dipteris.unige.it (C.N. Bianchi), valeriano.parravicini@gmail.com (V. Parravicini), slavorano@costaedutainment.it (S. Lavorano).

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a major component of management, as they allow for evaluating coral reef ecosystem health (Haynes et al., 2007; Parsons et al., 2008) following the initiatives undertaken, and ameliorate our understanding of ongoing trends (West and Salm, 2003). Hence, standardized monitoring programs are crucially important for the collection of large scale homogeneous and reliable information.

Beyond the assessment of coral species richness (Richards, 2013) which is rare and difficult to achieve, commonly used metrics of reef health are represented by the evaluation of the coral cover and coral recruitment (English et al., 1997). The former measures the consequences of disturbance. Reduced coral cover often implies lowered habitat provision and constructional capacity (Benzoni et al., 2003; Lasagna et al., 2010a; Graham et al., 2011), although the planar view offered by coral cover has been recently criticized (Goatley and Bellwood, 2011). On the contrary, measuring coral recruitment contributes to assess coral population dynamics and provides information on the recovery potential (Cardini et al., 2012; Salinas-de-León et al., 2013).

Sustained monitoring, however, would benefit from metrics that incorporate information on both consequences of disturbance and the recovery potential in order to get timely data on the prevailing health conditions of reef corals. Jameson et al. (1999) proposed a Coral Damage Index (CDI) based on the percentage of broken/overturned coral colonies and coral rubble to illustrate recent and past physical damages, respectively. This index does not take into consideration several common effects such as smothering, bleaching and death, which inherently express the severity of disturbance (Wittenberg and Hunte, 1992; Mascarelli and Bunkley-Williams, 1999; Lirman, 2000; Kumaraguru et al., 2005; Lesser et al., 2007).

In this paper, we introduce an index of reef coral condition that takes into account the relative abundance of coral colonies, ranked into six ordinal categories according to the degree of severity of their damage. As an example, we provide an application of this index to the coral reefs of the Maldives, one of the world regions most harshly struck by the global bleaching event of 1998 (Hayes and Strong, 2000) and presently experiencing growing tourism pressure (Anderson et al., 2010). In our application we focused on *Pocillopora* and tabular *Acropora*, which are dominant species across the Maldivian reefs and are known to be critically important for reef growth (Morri et al., 1995; Benzoni and Pichon, 2007; Bigot and Amir, 2012).

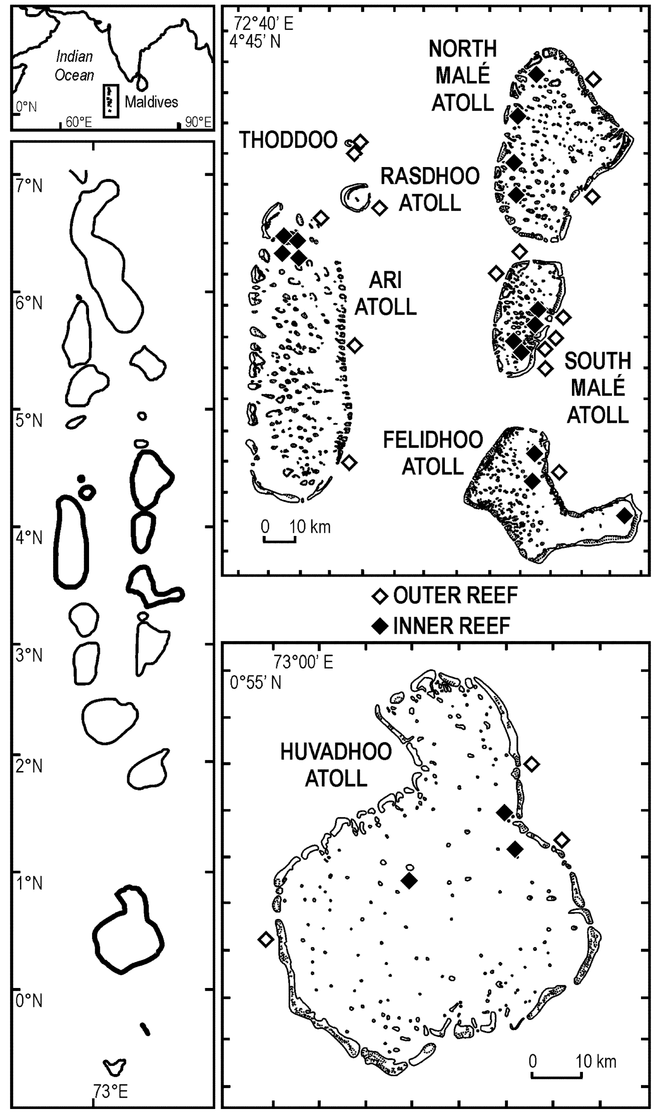

Fig. 1. Geographical setting of the study sites (diamonds) in the atolls of North Malé, South Malé, Felidhoo, Huvadhoo, Ari, Rasdhoo and Thoddoo in the Maldives.

2. Materials and methods

2.1. Study area

Notwithstanding a decadal history of local threats, including coral mining (Brown and Dunne, 1988), crown-of-thorn attacks (Ciarapica and Passeri, 1993) and tourism pressure (Allison, 1996), Maldivian coral reefs kept flourishing conditions, with hard coral cover often reaching 100% in shallow water and dominance of tabular *Acropora* and *Pocillopora* species (Ciarapica and Passeri, 1993; Bianchi et al., 1997, 2006a,b), up to the severe bleaching episode of 1998 (Morri et al., 2010). Bleaching caused high coral mortality and living coral cover dropped to 2–8% (McClanahan, 2000; Zahir, 2000; Edwards et al., 2001). Species of *Pocillopora* and tabular *Acropora* suffered whole-colony mortalities (around 90% on average) within 20 m depth (Bianchi et al., 2006a), with a virtual disappearance from Maldivian reefs (Schuhmacher et al., 2005; Lasagna et al., 2008). Soon after the mortality event, early signs of recovery were already evident (Bianchi et al., 2006b), but in 2004 the abundance of tabular *Acropora* and *Pocillopora* was still reduced with respect to the pre-1998 condition (Schuhmacher et al., 2005; Lasagna et al., 2010b). Recovery was still in progress when the Sumatra-Andaman tsunami of 2004 hit the easternmost Maldivian atolls (Gischler and Kikinger, 2006; Richmond et al., 2006). Tkachenko (2012) summarized recent environmental change of Maldivian coral reefs, while information on their biodiversity and geomorphology can be found in Andréfouët (2012) and Gischler et al. (2013), respectively.

2.2. Field activities

Our surveys took place from April 2005 to April 2010 in the atolls of North Malé, South Malé, Felidhoo, Huvadhoo (Suvadiva), Ari, Rasdhoo and Thoddoo (Fig. 1). Data were collected by SCUBA diving at three distinct depths (6, 12, and 18 m) in 2 reef types: outer reefs (ocean-facing sides of the atoll rim) and inner reefs (lagoon patch-reefs or lagoon-facing sides of the atoll rim). Sites were randomly located on a map (British Admiralty Chart No 1013) and their position was recorded using a GPS. Each year, nine 20×1 m belt transects (Bianchi et al., 2004) were laid parallel to the reef edge from an arbitrarily selected starting point at each depth for each reef type, to a total of 324 transects (Fig. 2). Within each transect, the number of tabular *Acropora* and *Pocillopora* colonies was counted and attributed to one of the following ordinal categories: (i) healthy coral, (ii) broken coral, (iii) upturned coral, (iv) smothered coral, (v)