Aquat. Living Resour. 18, 125–147 (2005)
© EDP Sciences, IFREMER, IRD 2005
DOI: 10.1051/alr:2005015
www.edpsciences.org/alr

Aquatic
Living
Resources

A review of selected indicators of particle, nutrient and metal inputs in coral reef lagoon systems

Renaud Fichez[1,a], Medhi Adjeroud[2], Yves-Marie Bozec[3], Ludovic Breau[4], Yannick Chancerelle[5], Christophe Chevillon[4], Pascal Douillet[4], Jean-Michel Fernandez[4], Patrick Frouin[6], Michel Kulbicki[2], Benjamin Moreton[4], Sylvain Ouillon[4], Claude Payri[4], Thierry Perez[1], Pierre Sasal[7] and Julien Thébault[8]

[1] Centre d'Océanologie de Marseille, Station Marine d'Endoume, rue de la batterie des lions, 13007 Marseille, France
[2] École Pratique des Hautes Études, laboratoire de biologie marine et malacologie, UMR 8046 CNRS, Université de Perpignan, 66860 Perpignan, France
[3] Agrocampus Rennes, Dép. halieutique UPR Mesh, 65 rue de St-Brieuc, CS 84215, 35042 Rennes Cedex, France
[4] Centre IRD de Nouméa, BP A5, 98848 Nouméa, New Caledonia
[5] CRIOBE, BP 1013, Papetoai, Moorea, French Polynesia
[6] Laboratoire d'Écologie Marine, Université de la Réunion, BP 7151, 97715 Saint-Denis Cedex 9, France
[7] Centre de Biologie et d'Écologie Tropicale et Méditerranéenne, UMR 5555 CNRS, Université de Perpignan, avenue Paul Alduy, 66860 Perpignan Cedex, France
[8] Centre IRD de Brest, BP 70, 29280 Plouzané Cedex, France

Received 3 September 2004; Accepted 30 May 2005

Abstract – This review presents environmental and biological indicators of the impact of three major categories of inputs in coral reef lagoons i.e. particles, nutrients and metals. Information was synthesized to extract well established indicators together with some interesting new concepts currently under development, and to provide the reader with an assessment of their respective advantages and drawbacks. The paper has been organized according to the capacity of three categories of indicators to respond either in a specific or a non specific way to a given source of input. The first section focuses on abiotic indicators which main interest is to respond instantaneously and in a truly specific way to a given source of input. The second and third sections present informations on bioindicators either at the sub-individual level or at the individual to community level, indicator specificity generally decreasing as a direct function of biological or ecological complexity. This review showed that even though significant work has already been done on coral reef ecosystems, much more scientific studies are still needed to answer the growing local demands for simple and truly validated tools to be used in environmental surveys. It is further stressed that, due to the biological and environmental diversity of coral reef lagoons, a preliminary step of on-site validation must be considered as an absolute prerequisite when indicators are planned to be used in the frame of a local environmental monitoring programme.

Key words: Coral reef / Lagoon / Sediment load / Eutrophication / Metals / Pollution / Abiotic indicators / Bioindicators / Biomarkers

Résumé – Cette synthèse bibliographique présente les caractéristiques environnementales et biologiques pouvant être utilisées comme indicateurs des effets de trois grandes catégories d'apports exogènes dans les milieux récifo-lagonaires : les particules, les éléments nutritifs et les métaux. Les données de la littérature ont été analysées pour en extraire des indicateurs reconnus ainsi que de nouveaux concepts en cours de développement, et afin d'examiner leurs avantages et inconvénients respectifs. L'article a été structuré selon la capacité de trois types d'indicateurs à répondre de manière spécifique ou non spécifique à l'une des trois catégories d'apports cités précédemment. En premier lieu, les indicateurs abiotiques qui ont pour principal intérêt de répondre instantanément et spécifiquement à l'un des trois types d'apports, puis les bio-indicateurs respectivement considérés à l'échelle infra-organisme ou à une échelle allant de l'organisme à la communauté. La spécificité de ces indicateurs diminuant en fonction de l'augmentation de la complexité biologique et écologique. Bien qu'il existe déjà un nombre important de travaux portant sur les systèmes récifo-lagonaires, un effort scientifique majeur reste nécessaire pour répondre à des demandes croissantes de définition d'outils simples et validés pouvant être utilisés dans le cadre de la surveillance de l'environnement. De plus, et compte tenu de la diversité biologique et environnementale des lagons et des récifs coralliens cette étude montre que l'utilisation d'indicateurs, dans le cadre de programmes de suivi environnementaux à l'échelle locale, passe par une phase préliminaire indispensable de validation sur site, des indicateurs sélectionnés.

---

[a] Corresponding author: `fichez@com.univ-mrs.fr`

1 Introduction

Monitoring coastal zones to assess and control environmental stress is a worldwide issue that receives growing attention. Coral reefs and coral reef lagoon ecosystems are known for their extreme biodiversity and trophic complexity and they will respond to environmental stress in a complex way. Additionally, background environmental information in those tropical systems is often weaker and sparser than in temperate systems. Such specificities and the hitherto need for adapted response in term of environmental monitoring must be taken into account. This paper specifically focuses on 3 major terrigeneous and anthropogenic inputs that rank among the most acute and widespread causes of environmental alteration i.e. particles, nutrients and metals. It is aimed at synthetically presenting some existing or promising indicators of environmental stress related to those 3 major inputs in coral reef lagoon environments.

As a general definition, we may retain that an indicator is a sign or signal that relays a complex message, potentially from numerous sources, in a simplified and useful manner and that its primary uses are to characterize current status and to track or predict significant change (Jameson et al. 1998). Indicators include a measure, an index of measures, or a model that characterizes the studied systems, coral reef and coral reef lagoon ecosystems in the present case, or one of their critical components. Physical and chemical signals may serve as indicators of specific anthropogenic influences. Direct measurement of environmental stress however requires knowledge of critical or threshold levels of stress (Hughes 2002), a prerequisite that is often far from clearly established especially as environmental conditions in human impacted coral reef lagoons display significant temporal and spatial variability. Biological responses to environmental conditions form another category of indicators known as bioindicators. A bioindicator is an anthropogenically-induced response in biomolecular, biochemical, or physiological parameters that has been causally linked to biological effects at one or more of the organism, population, community, or ecosystem levels of biological organization (Mc Carty and Munkittrick 1996). Bio-indicators and to a lesser extent environmental indicators received considerable attention in the past and a large number of relevant article and book references can be found in the literature (reviews in Kaiser et al. 2001; Market et al. 2003). Published works specifically dealing with indicators in coral reef and coral reef lagoon environments are much rarer and mostly refer to bioindicators (Linton and Warmer 2003; Garzon-Ferreira et al. 2005) and more rarely to environmental indicators (Moss et al. 2005), the concept of ecological indicator being apparently more commonly used in coral reef management research (Castro 2001; Hugues 2002). Analysis of the existing literature showed that a concise review on indicators of the fate and impact of particle, nutrient and metal inputs in coral reef ecosystems was missing. This statement was further confirmed by environmental managers who claimed to be confronted with confuse and incomplete informations when digging the literature for indicators adapted to their specific and precise needs. This paper hence was designed to fill this gap and has been organized in 3 sections regrouping (i) abiotic environmental indicators of the origin and fate of specific anthropogenic input sources, (ii) indicators at the organism level ranging from biochemical to bioenergetic responses and (iii) indicators at the population and community level responding to environmental stress on a long term basis. For each of these sections a distinction was made between indicators providing a specific or a non-specific response to one of the 3 sources of inputs.

2 Abiotic environmental indicators

Physical and chemical descriptors of environmental conditions come in such numbers that environmental impact assessment studies are often overburdened with irrelevant data, the main defaults being that:

- The specificity of analytical methods requested to analyze tropical lagoon waters are often poorly mastered especially by unspecialized analytical contractors (i.e. nutrient analytical techniques unadapted to oligotrophic waters).
- The importance of temporal variability which can be extreme in coral reef systems is often neglected leading to potentially inconsistent definition of background environmental conditions.
- Data interpretation is often hastily presented and poorly mastered.

Therefore, environmental managers may feel lost in a maze of irrelevant information from which they are unable to extract efficient and cost effective indicators of environmental quality truly adapted to the problem they are confronted with. Here we propose a deliberately short listed selection of parameters together with a brief overview of their main advantages and disadvantages (Table 1).

2.1 Abiotic environmental indicators of particle inputs

Suspended load versus turbidity

Suspended particle matter (SPM) inputs directly affect light penetration and sedimentation rates, two factors that strongly influence the equilibrium of coral reef ecosystems (Woolfe and Larcombe 1999). Filtration of water and weighing of the filtered material, a technique initially designed to assess suspended loads in turbid waters, has been largely applied to marine water. Application of this apparently simple method to tropical marine water with low suspended load may prove far from satisfactory and must be regarded with caution. On a technical point of view glass fibre filters must be averted because they may lose weight during the sample treatment process hence strongly impacting the calculation of suspended load. In situ optical turbidity measurement (transmissometry, back-scattering) has been increasingly used during the past decades and an intercomparison exercise concluded that in waters with low SPM concentrations, turbidity measurement was more accurate than filtration-weighing techniques (Mc Girr 1974). A special mention goes to particle backscattering which offers a wide measuring range adapted to the study of land-ocean transects and benefits from a single optical surface for which automated cleaning systems have been designed to prevent fouling hence allowing for long term *in situ* deployment (Ridd and Larcombe 1994).

Table 1. Abiotic indicators.

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Location of studies on reef lagoons	References
Particles inputs							
Suspended particulate matter	Filtering	Strickland and Parsons 1972	Simplest and most frequently used method but often discarded in scientific papers	Strong variability mainly derived to the low retained weight versus much higher filter weight	Filtration of a large volume of water Weighing in strictly dry conditions	French Polynesia	Blanchot et al. 1989
Turbidity in situ	Light transmission or backscattering	Mc Girr 1974	High frequency data acquisition (profiling) Continuous recording (with automated cleaning systems)	Signal depending on particle optical properties	Local calibration needed to derive SPM load from NTU ($1 \text{ NTU} \simeq 1 \text{ mg L}^{-1}$)	French Polynesia New Caledonia Papua New Guinea Great Barrier Reef	Adjeroud, 2000 Ouillon et al. 2004 Thomas et al. 2003 Orpin et al. 2004
Vertical particle flux	Sediment traps	Butman 1986 Butman et al. 1986	Integrative information	Combined primary and secondary flux in shallow water	To be used in depth greater than 15 m Trap aspect ratio ≥ 2.5	French Polynesia New Caledonia Venezuela	Charpy and Charpy-Roubaud 1991 Schrimm et al. 2002 Clavier et al. 1995 Bastidas et al. 1999
Sediment carbonates	Acid dissolution or CHN analysis	Masse et al. 1989	Simple assessment of lagoon (carbonate) vs. terrigeneous (non-carbonate) sediments	Ineffective for carbonated land masses		Florida Comoro islands	Gaccia et al, 2003 Masse et al. 1989
Acoustic mapping	Acoustic ground discrimination system	Hamilton et al. 1999	High data acquisition rate Real time mapping Additional information on benthic habitats	Local validation needed Response function of sensor	A new area of technical development with strong potential for environmental studies	Great Barrier Reef Philippines New Caledonia	Hamilton et al. 1999 White et al. 2003
Inorganic and organic nutrient inputs							
Dissolved and particulate nutrients in the water	Various techniques	Strickland and Parsons 1972 Raimbault et al. 1990 Holmes et al. 1999	Precise technique Direct assessment of nutrient levels	High environmental variability High technical skill Sophisticated equipment	Priority to nutrient limiting primary production Techniques adapted to low concentrations (NO_3, NH_4)	Bahamas French Polynesia French Polynesia	Lapointe et al. 2004 Pages et al. 2001 Charpy et al. 1997
Nutrients in sediment (particles and pore water)	Various techniques	Strickland and Parsons 1972	Moderately simple	Most of the degradation process occurs at the sediment-water interface Same as above	Poor indicator of trophic status		Charpy-Roubaud et al. 1996
Vertical particulate nutrient flux	Sediment trap and various nutrient analysis	See vertical particle flux, dissolved and particulate nutrients	Same as for suspended particulate matter	Same as for suspended particulate matter Alteration of organic material Bias due to resuspension	To be used in depth greater than 15 m	Japan French Polynesia	Hata et al. 2002 Schrimm et al. 2002

Table 1. Continued.

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Location of studies on reef lagoons	References
Benthic metabolism and nutrient flux	Various in situ and ex situ techniques	Yates and Halley 2003 Viollier et al. 2003 Grenz et al. 2003	Truly mirroring the benthic trophic status	Complicated techniques requiring strong technical skill and equipment		Japan Kenya New Caledonia Great Barrier Reef	Hata et al. 2002 Mwashote and Jumba 2002 Clavier and Garrigue, 1999 Grenz et al. 2003 Rasheed et al. 2004 Clavier et al. 2005
Metal inputs							
Dissolved metals	Diffusive gradients in thin films (DGT) integrative resin	Zhang and Davison 2000 Webb and Keough 2002	Simple handling Integrated information Low contamination risk Potential alternative to bioindicators	Complex analysis generally requiring ICP-MS detection New tool in need of additional testing	Complex analytical step to be contracted with a qualified laboratory	Not applied yet in coral reef environments Experimental work underway in New Caledonia (Thébault pers. comm.)	
Dissolved metals in pore water	DGT integrative resin	Fones et al. 2001	Simple handling Integrated information Low contamination risk	Id.	Id.	Not applied yet in coral reef environments	
Metals in the sediment	Total mineralization	Loring and Rantala 1972	Time integrated information	No indication on the bioavailable metals	Good indicator of metal inputs Poor indicator of the potential effects on biota	Great Barrier Reef Torres straight Fiji Florida Keys Venezuela Philippines	Haynes and Johnson 2000 Haynes and Kwan 2002 Morisson et al. 2001 Gaccia et al. 2003 Bastidas et al. 1999 David 2002
Bioavailable metals in the sediment	Sequential extraction	Tack and Verloo 1999 Rauret et al. 1999	Time integrated information	Not directly related to bioavailable metals Complex technical steps	Moderately good indicator of the potential effects on biota	Great Barrier Reef French Polynesia (Tahiti) New Caledonia	Reichelt and Jones 1994 Esslemont 2000 Harris 1998 Fernandez et al. 2002 Fichez et al. 2005

Vertical particle flux

Particle vertical flux measurement provides a dynamic assessment of deposition process which is directly related to environmental stress. When combined with additional chemical analysis of the settling particles it further provides information on the flux of contaminants reaching the benthic boundary layer. However, sediment traps used to assess the vertical particle flux have been demonstrated as hydrodynamically intrusive their design strongly influencing collecting efficiency (Asper 1987; Gardner 2000). Furthermore, the validity of data acquired in shallow and hydrodynamically active environments has been questioned as sediment traps indistinctively collect primary (non resuspended) and secondary (resuspended) fluxes and great caution must be taken when using this technique to assess particle settling fluxes in coastal environments (McComb 2001).

Sediment composition

Terrigenous indicators in coral reef lagoon sediments may be inferred from a qualitative and quantitative analysis of the skeletal composition (Masse et al. 1989). Lagoon sediments are essentially originating from: coastal terrigenous inputs, barrier reef inputs and authigenic benthic and pelagic productions (Chevillon 1996). Autochthonous benthic production is essentially represented by molluscs, foraminifers and *Halimeda* bioclasts. Influence from the barrier reef is evidenced by the presence of non free-living coral debris, specific foraminifera species or hard grounds calcareous algae, while coastal terrigeneous influence is materialized by lithoclasts.

When coral reefs develop along non calcareous land, a second and much simpler way to detect terrigeneous versus non terrigeneous inputs in lagoon sediments is to measure their carbonate content. In such conditions, carbonates exclusively originate from reef and lagoon origins and the non carbonate fraction is essentially composed of terrigeneous particles plus some biologically formed silicate and organic material. The contribution of biogenic silicate and organic material has been evaluated to around 10% of total sediment in atoll lagoons (Chevillon 1992) so it is possible to consider that in lagoon sediments the fraction of non carbonate material in excess of 10% of the carbonate material can be attributed to allochtonous inputs of terrigeneous material.

Very recently, Acoustic Ground Discrimination Systems (AGDS) have been used as a mean to rapidly map sediment and habitat distributions (Hamilton et al. 1999) and this new technique already largely used on fishing boats certainly will be increasingly involved in rapid environmental surveys of silting areas.

2.2 Abiotic environmental indicators of nutrient inputs

Nutrients

Even though they can't be used alone to establish the trophic status of a coral reef system (Koop et al. 2001) nutrient concentrations still stand as a key parameter to environmental surveys (Table 1). Nutrients come in various dissolved and particulate forms and in environmental assessment studies priority should obviously been given to the inorganic nutrient forms that are limiting to primary production. In coral reef lagoons as in most coastal zones, phosphorus and nitrogen generally are the main factors limiting primary production (Smith 1984) but in lagoons with significant oceanic water inputs nitrogen generally is the essential limiting factor. In such a trophic context ammonia (NH_4) would stand as best candidate to trace reduced nitrogen inputs especially those delivered by waste water release while nitrate + nitrite (NO_3+ NO_2) would stand as best candidates to trace oxidized nitrogen inputs such as those originating from run-off or intensive fertilizer use. Silica is rarely presented as a limiting nutrient in coral reef lagoons so, unless specific justification for its measurement can be provided, it is of limited relevance to environmental monitoring.

Nutrient in sediments and nutrient vertical particle flux

Benthic biodiversity, biomass or metabolism, have been tentatively linked with quantitative approaches of sediment organic and inorganic nutrient load. However, deposited sediments are the end products of a succession of degradation processes and studying non conservative tracers such as nutrients is of limited sense to assess the impact of anthropogenic inputs. In coral reef environments like in almost all coastal systems, most of the energetic exchanges between settling material and benthic biota take place at the water-sediment interface and little energy remains bellow the sediment surface as shown by the very low organic matter content of lagoon sediments (Brunskill et al. 2002) hence quantification of bioreactive compounds in sediments must be considered as a poor indicator of trophic status.

Measuring the flux of incoming nutrients attached to settling particles collected by sediment traps is a much more complicated but much more meaningful way of quantitatively assessing the impact of nutrient inputs. Such techniques have mostly been used in studies assessing reef budget and export of nutrients (Table 1) in coral reef environments of more than 20 m depth but are also conducted in unpublished environmental assessment studies or environmental monitoring including large scale initiatives such as the USGS Coral Reef Studies in Hawaii or the Coral Reef Evaluation and Monitoring Programme in Florida. Reserves concerning the use of sediment traps in coastal environments have been addressed in the "vertical particle flux" section.

The measurement of nutrient fluxes at the water-sediment interface is another powerful integrative indicator of nutrient inputs and trophic status as benthic biota is strongly depending on the flux of organic and inorganic nutrients reaching the benthic boundary layer (Sorokin 1993). The respective interests and limits of *in situ* versus ex situ techniques (Table 1) in coral reef environments have been recently discussed but each technique requires extensive technical skill and equipment limiting this type of approach to very detailed environmental assessment studies.

2.3 Abiotic environmental indicators of metal inputs

Metals in the water

The quantitative determination of dissolved trace elements in sea water is a critical issue and direct determination is generally impossible because of the high amount of major elements. Analytical techniques increasingly rely on ion exchange resins but due to the technical complexity of those techniques and the ambient variability in metal concentrations a review on those methods is beyond the scope of this article. However, an interesting technical development have been recently derived from ion exchange resins to produce an *in-situ* trace metal preconcentration device known as DGT, for Diffusive Gradients in Thin films (Zhang et al. 2002). A DGT allegedly retains free inorganic ions and labile organic species, i.e., those forms that are considered as the most bio-available to marine organisms even though the concept of a bioavailable fraction is in itself still part of a fierce debate (Meyer 2002). By providing a proxy to *in situ* dissolved bioavailable metal concentrations, the DGT technique could represent an alternative or at least a complement to bio monitoring of trace metals in coral reef environments.

Metals in sediments

Bulk metal concentrations in sediment provide information on metal inputs but do not directly relate to a potential impact on the biota. Various geochemical methods based on selective extraction procedures have been proposed to assess the bioavailable fraction (see review in Tack and Verloo 1995) and severe criticisms have been raised mainly due to lack of selectivity, the diversity of existing approaches or the absence of comparative studies and subsequent absence of true validation. Recently, a European Community initiative proposed a standardized sequential extraction method associated with the distribution of certified reference material (Rauret et al. 1999). Practically, metal analysis in sediment requires significant technical skill and is altogether expensive and time consuming especially if selective extraction is considered. As a consequence such geochemical approaches must be limited to specific cases where human impacts such as mining activities or industrial spillage occur and hence where identification of inputs and distribution of bio-available metals is essential.

3 Indicators at sub-organism level

3.1 Sub-organism bioindicators of nutrient inputs

Nutrient ratio and nitrogen stable isotopes

N/P ratio in algae tissue is known as a time integrated indicator of nutrient uptake and of the relative availability of nitrogen and phosphorus to the algae (Horrocks et al. 1995) but this parameter is very variable in tropical algae or seagrasses (Yamamuro et al. 2003) and should be used with great care

Marine, terrigeneous and anthropogenic nutrient input sources may have significantly different nitrogen stable isotope signatures. Even though fractionation may occur along the food chain, δ15N ratios in tissues generally reflect the respective influences of those sources. Curiously, little work has been done in coral reef systems and most of it dealt with scleractinian corals (Mendes et al. 1997; Heikoop et al. 2000) and very rarely with other groups such as algae (Grice et al. 1996), seagrasses (Yamamuro et al. 2003) or crustacean (Risk and Erdemann 2000). Stable isotope analysis is a sophisticated tool but, due to the paucity of reliable alternative, it should be considered as a potentially valuable indicator of nutrient inputs.

3.2 Sub-organism bioindicators of metal inputs

Metal bioaccumulation in soft tissues

The use of bioaccumulating species to monitor the distribution and temporal variations of bioavailable metals (and other chemicals) in estuarine and coastal environments offers many advantages. By definition, bioaccumulating organisms have high metal concentrations in their tissues, a factor which strongly lowers analytical constraints. Bioaccumulators also provide a time integrated measurements of the bioavailable and potentially toxic fraction of metals (Rainbow 1995). However, many biotic factors such as age (hence size and growth rate) and physiological condition (related to reproduction and trophic status) influence bioaccumulation and must be studied before a reliable interpretation of the data can be reached (Langston and Spence 1995).

Ideal biomonitors must fulfil many ecological and biological criteria (Rainbow 1995; Langston and Spence 1995), thus drastically limiting the number of potential candidates. Numerous studies have been conducted in temperate systems and bivalves (oysters and mussels) have been selected as key biomonitors within the frame of national and international programmes such as the Mussel Watch (O'Connor et al. 1994). Few studies have been conducted to establish metal baseline levels in biota and to identify suitable biomonitors in tropical regions (Peters et al. 1997). A bibliographic study (Table 3) showed that most studies were conducted in South East Asia, Northern Australia, India as well as Brazil and southern Mexico, whereas many other tropical areas such as the Pacific and Caribbean islands suffered from an obvious lack of knowledge. Consequently, laboratory experiments and *in situ* validation of biomonitors are urgently needed in many tropical regions to identify bioaccumulating species and to define the biological processes governing metal accumulation. It is important to remind the reader that a proper assessment of environmental contamination must be based on a multi species biomonitoring and that in tropical systems known for their huge biodiversity investigations generally have to be conducted at a local scale. Economic costs inherent to the local development of such studies on bioindicators certainly represent the main limitation to their use in tropical countries.

Skeletal composition as proxy to metal inputs

Since the early seventies and the work by Livingston and Thompson (1971), many studies focused on the use of marine skeletons (e.g. scleractinian corals, bivalves) as proxy to environmental contamination by heavy metals. Calcifying organisms such as corals and bivalves incorporate metals in the carbonate frame, generally as a function of their concentration in the environment. Moreover, most coral and bivalve species are known to form periodic banding patterns and the analysis of metals in growth bands provide a way to reconstruct the evolution of heavy metal concentrations over long periods of time for corals (century with week to annual resolutions), and shorter periods for bivalves (years with day to seasonal resolutions). Many studies have been conducted in tropical environments using scleractinian corals (Table 2), generally to assess the potential effect of industrial activities, e.g. ore mining and

Table 2. Bioindicators at suborganism level (+ Refer to papers in last column).

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Tropical target species	References
Bioindicators of nutrient inputs at sub-organism level							
Nitrogen stable isotopes	Stable isotope ICP-MS	+	Rare indicator to trace nutrient inputs	High technical skill and equipment Terrigeneous vs. marine stable isotope signatures generally less marked in tropical than temperate systems	Identification of endpoint sources signatures	Scleractinian corals	Mendes et al. 1997, Heikoop et al. 2000
						Algae	Grice et al. 1996
						Crustacean	Risk and Erdemann 2000
Bioindicators of metal inputs at sub-organism level							
Metals in soft tissues	Various sampling and analytical techniques used	Langston and Spence 1995 Rainbow 1995	True indicators of bioavailable metals Temporal integration Bypass most technical problems encountered when analysing metals in the water	Non absolute tools that require preliminary local investigation Possible differences in the regulation of different metals Complex physiological response due to symbiotic algae (giant clams, scleractinian corals) Taxonomic confusion	Use a combination of bioindicator to assess multiple sources of metal contamination When available prefer microwave extraction to classical heating techniques	Multiple	Breau 2003
						Algae	Denton and Burdon-Jones 1986 Ramirez et al. 1990 Serfor-Armah et al. 2001
						Sponges	Patel et al. 1985
						Scleractinian corals	Hanna and Muir 1990 Esslemont 2000
						Soft corals	Denton and Burdon-Jones 1986 Glynn et al. 1989 Jaffé et al. 1992
						Echinoderms	Laboy-Nieves and Conde 2001 Rojas et al. 1998 Maven et al. 1995
						Molluscs	Cheung and Wong 1997 Jaffé et al. 1998 Rayment and Barry 2000 Roméo et al. 2000 Hung et al. 2001 Khristoforova et al. 2003
						Ascidians	Monniot et al. 1994
Skeletal proxies	Various sampling and analytical techniques used	+	Temporal integration Yearly to daily resolution depending en species growth rate	High technical skill and instrumentation	Cautious determination of growth rate and banding pattern periodicity Cautious sampling to avoid metal contamination	Scleractinian corals	Bastidas and Garcia 1999 Fallon et al. 2002 David 2003 Runnalls and Coleman 2003 Inoue et al. 2004 Ramos et al. 2004

Table 2. Continued.

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Tropical target species	References
Bioassays	Gametes and larval sensitivity to metals	Rumbold and Snedaker 1997	Early detection of metal contamination	Experimental procedures High technical skill	To be used in complement to other longer term bio-indicators	Scleractinian corals	Reichelt-Brushett and Harrison 2000 Negri and Heyward 2001
						Echinoderms	Kobayashi 1994 Ringwood 1992
						Molluscs	Ringwood 1991, 1993
Non specific bioindicators at sub-organism level							
Biochemical markers							
Heat Shock Proteins	Molecular characterization	Sanders 1993	Temperature dependent	High technical skill and instruments		Scleractinian corals	Tom et al. 1999 Downs et al. 2000 Rossi and Snyder 2001
RNA/DNA ratios		+		High technical skill and instruments		Scleractinian corals	Meesters et al. 2002
Lipid concentrations	Colorimetric titration	+				Scleractinian corals	Harriot 1993
Protein and free amino-acid concentrations	HPLC	+		High technical skill and instruments		Scleractinian corals	Kendall et al. 1987
ATP concentrations	Bioluminescence	+		High technical skill and instruments		Scleractinian corals	Fang et al. 1987
Cytological markers							
Lysosomal stability	Neutral red retention assay on blood and hepatopancreas	Lowe et al. 1995	Most widely used sub cellular unspecific biomarker	High technical skill		Never used in tropical conditions	
Physiological markers							
Condition indices	Biometric	Nicholson 1999	Simple	Moderately sensitive		Never used in tropical conditions	
Stress on stress response	Survival to air exposure	Variego et al. 1995	Simple	Moderately sensitive		Never used in tropical conditions	
Energy balance	P:R, Scope For Growth	Widdows et al. 1995	Good sensitivity	Almost no existing work on tropical species Complex physiological response due to symbiotic algae (giant clams)		Molluscs	Bourdelin 1996 Elfwing et al. 2003
Structural markers							
Diseases incidence and virulence	Observation, tissue analysis	Harvell et al. 1999	Ecological relevance Simple techniques		Interest for environmental monitoring program	Octocorallian	Garzon Ferreira and Zea 1992 Smith et al. 1996 Nagelkerken et al. 1997

processing (Bastidas and Garcia 1999; Fallon et al. 2002). Numerous papers have been published on the use of temperate bivalve shells as proxy to environmental changes (Labonne et al. 1998; Szefer et al. 2002) but no conclusive results have been presented for tropical bivalves even though target species such as giant clams received some significant attention.

Bioassays

Bioassays have been widely used to assess bioavailability and toxicity of chemical contaminants in aquatic environments (Widdows et al. 1995). Bioassays largely rely on biological responses or endpoints (lethal or sub lethal effects as well as behavioural responses) in organisms (adults, juveniles or embryos/larvae) or gametes experimentally exposed to field-collected or in situ effluents, seawater, sediments or aqueous extracts of sediments. Since early-life stages are known to be more sensitive to contaminants than adults, bioassays involving gametes, embryos, and larvae of marine invertebrates (generally bivalves and sea urchins) or fishes have been preferentially developed. Embryos and larvae can be experimentally obtained from in vitro fertilization using gametes released by mature adults. Non expensive, short-term (i.e. generally 24 h to 48 h) experiments can be conducted to test environmental samples, providing quick results generally expressed as percentages of inhibition of fertilization or embryo-larval development delay as well as morphological abnormalities, settlement success or even lethality. These physiological and morphological biomarkers are generally not specific of a given source of contaminant input.

Such toxicity tests conducted for known concentrations of several contaminants (mostly metals, hydrocarbons and pesticides) have recently been developed in tropical and subtropical regions to identify suitable target-species and establish related benchmarks, a necessary step to define bioassays suitable for ecological risk assessments (Peters et al. 1997). However, very few works involving *in situ* bioassays or laboratory exposure to field-collected seawater or sediment samples have been conducted to date in coastal tropical and subtropical waters (Rumbold and Snedeker 1999; Nascimento et al. 2000).

Bioassays allow for an early detection of environmental stress and are by definition of high ecotoxicological relevance. They also are of ecological relevance at the population level when earlylife stages and reproductive endpoints are studied. However, the biological sensitivity to a specific pollutant varies from one species to another and is also a function of the development stage. A realistic assessment of biological impacts of chemical contamination therefore implies the use of different target-species, life stages and endpoints. Existing studies demonstrated bioassay to be of great potential in understanding and assessing biological effects of chemical toxicants inputs in tropical coastal ecosystems and significant additional efforts are strongly needed.

3.3 Sub-organism non specific bioindicators

Biomarkers reflect stress exposure or effects at molecular, cellular or physiological levels. Biodiversity loss, widespread mortality and other population-level effects manifest themselves long after biochemical dysfunction, physiological abnormalities, growth or reproduction impairment, and ecologically important changes have occurred as a result of environmental degradation. Non-specific (generic) biomarkers hence may represent the earliest signs of ecological alteration. Biomarkers are employed within the framework of many temperate marine ecosystems monitoring networks but their use in tropical coastal waters is surprisingly scarce. Valuable early warning tools may be derived from biological responses to environmental stress and an overview on generic biomarkers is presented.

Biochemical markers

Downs et al. (2000) recently proposed a Molecular Biomarker System (MBS) to characterize the physiological status of corals (*Montastrea faveolata*) challenged by heat stress and bleaching that included several molecular parameters considered as generic biomarkers. Among them, the so-called families of “Heat Shock Proteins (HSP)” are ubiquitous chaperones found in all phyla, essential for cellular function, and well known to be up-regulated after exposure to several stress (Sanders 1993; Table 2). The role of these stress proteins in marine organisms was first established as a physiological response to temperature changes in molluscs (Sanders 1988). Molecular characterization of HSP in corals is recent (Tom et al. 1999), and mainly linked to stresses such as intra or inter-specific competition for space (Rossi and Snyder 2001) or experimental heat shock (Downs et al. 2000). The sole field study of HSP in corals revealed that samples taken from a stressed area (hypersedimentation and combined pollution) had a higher HSP90 level than those from a non-stressed area (Wiens et al. 2000). Similar studies have been successfully conducted on sponges, either experimentally (Koziol 1998) or in the field (Perez 2001). Unfortunately, tropical sponges have never been studied but HSP certainly is a promising generic biomarker for assessing the health of reef invertebrates.

Other biochemical signatures have been identified in scleractinian corals as indicators of stress and especially of sediment/turbidity stress, eventhough they cannot be considered as truly specific (Table 2).

Cytological markers

Lysosomal stability is one of the most widely used subcellular generic biomarkers. The lysosom-rich (digestive) cells of the molluscan hepatopancreas are frequent targets for the toxic action of many environmental stressors and lysosomes are thus considered as indicators of pollutant-induced cell injuries (Moore 1990). Degradation of lysosomal membranes has been quantitatively related to stress exposure of several tropical molluscs, among which the green mussel *Perna viridis* (Cheung et al. 1998; Nicholson 1999) is broadly distributed in the Indo-Pacific. Effects of perturbation have been measured along a well defined pollution gradient either on indigenous populations (Cheung et al. 1998) or on transplanted individuals (Nicholson 1999). Among the different available techniques, the neutral red retention assay on blood and hepatopancreas cells (Lowe et al. 1995) is well standardised and applied in several monitoring programmes.

Table 3. Indicators at organism to population levels (+ Refer to papers in last column; Unspec. Unspecific of a given input).

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Tropical target group/species	References
Bioindicators of particle inputs at organism to population levels							
Coral cover / coral diversity	Census / taxonomy	+	Related to key biological target	Unspecific	Related to the use of unspecific bioindicators	Scleractinian corals	Adjeroud 1997 Brown et al. 2002
Bioindicators of nutrient inputs at organism to population levels							
Phytoplankton biomass	Fluorometry (recommended)	Lorenzen 1966	Precise and simple technique	No absolute threshold Strong spatial and temporal variability	Background levels to be carefully established at local scale	Phytoplankton	Sorokin 1995 Charpy 1996
Phytoplankton production	^{14}C	Steemann-Nielsen 1951	Directly linked to eutrophication	Complex techniques Use of radioactive tracers	Scientific expertise only	Phytoplankton	Furnas et al. 1990 Delesalle et al. 1993 Charpy 1996
Phytoplankton class size	Filtration Microscope Flow cytometry	+	Increase in plankton size as a function of trophic status	Time consuming techniques		Phytoplankton	Charpy and Blanchot 1998 Delesalle et al. 2001
Benthic algae abundance	Abundance Growth rate Production	+	Requires moderate skill	Poor specificity Also a function of herbivory activity	Ambiguous indicator To be used with caution preferentially as part of temporal surveys	*Enteromorpha* spp. *Dictyosphaeria cavernosa* *Sargassum* spp. Crustose coralline algae Cyanobacteria	Fong et al. 1993 Stimson et al. 2001 Schaffelke 2001 Fabricius and De'ath 2001 Thacker et al. 2001
Bulk benthic algae biomass	Biomass	+	Simple	Poor specificity Also a function of herbivory activity	Ambiguous indicator To be used with caution preferentially as part of temporal surveys	Benthic algae	Hugues 1994 Hugues et al. 1999
Coral cover	Census	+	Related to key biological target	Unspecific	Related to the use of unspecific bioindicators	Scleractinian corals	Birkeland 1977 Mc Cook 1999 Mc Cook et al. 2001
Non specific bioindicators at organism to population levels							
Morphology	Coral morphology triangle, skeletal density, etc.	+	Simple	Unspec.	+	Scleractinian corals	Atkinson et al. 1995 Steven and Broadbent 1997 Barnes et Lough 1992
Growth	Growth of adult colonies or transplants, tissue regeneration, etc.	+	Moderately complicated Experimental perspectives	Unspec.	+	Scleractinian corals	Guzman et al. 1994 Meesters and Bak 1993
Metabolism	Fecundity, recruitment rates, vitality index, reef health index, etc.	+	Rapid response to stress	Unspec.	+	Scleractinian corals	Ward and Harrison 2000 Miller and Barimo 2002 Gomez et al. 1994 Ginsburg et al. 1996 Hodgson 1999

Table 3. Continued.

Descriptors	Techniques	Technical references	Advantages	Major drawbacks	Recommendations	Tropical target group/species	References
Bioerosion	Occurrence, surface, growth forms of borers and assessment of bioerosion	+	Integrative response at community level	Unspec.	+	Cyanobacteria Clionid sponges Polychaetes Sipunculids	Cuet et al. 1988 Holmes 2000 Holmes et al. 2000 Hutchings and Peyrot-Clausade 2002
Population structure	Size frequency, demographic structure etc.	+	Integrative response at community level	Unspec. Mid to long term responses	+	Soft bottom macrofauna Scleractinian corals Parasites	Frouin 2000 Jameson et al. 2001 Bak and Meesters 1999 Meesters et al. 2001 Morand et al. 2000
Group community structure	Diversity index, rarity index, inventory, etc.	+	Integrative response at community level	Unspec. Mid to long term responses	+	Soft bottom macrofauna Benthic alga Sponges Scleractinian corals Parasites	Frouin 2000 Jameson et al. 2001 Stimson et al. 2001 Schaffelke 2001 Fabricius and De'ath 2001 Alcolado 1994 Done 1995, DeVantier et al. 1998 Cribb et al. 2000 Morand et al. 2000
Field survey of dominant species	Permanent quadra, Manta tow survey, line intercept transects, etc.	+	Moderate systematic knowledge generally required	Unspec.	+	Sponges and scleractinian corals	English et al. 1997 Wilkinson and Cheshire 1990
Inter-community dominance ratio	Field survey of surface coverage and data statistical treatment	+	Low systematic knowledge generally required	Unspec.	+	Scleractinain corals/ Sponges Scleractinian/ Benthic algae	Zea 1994 Mc Cook 1999 Miller et al. 1999
Global community structure	Remote sensing	Andréfouet et al. 2003	Large scale mapping of reef health Increasing resolution with new satellites	High technical competence	A technique boosted by technical improvements and with strong development potential	Global community	Andréfouet et al. 2003 Bouvet et al. 2003

Physiological markers in molluscs

Environmental stress depletes energy reserves and therefore has a depleting effect on growth that can be estimated through several indicators. "Condition indices" are probably the easiest parameter to obtain as it only requires measurement of basic biological parameters such as shell length, shell weight and soft tissue weight. It has been widely applied to bivalves and to green mussels (Cheung et al. 1998; Nicholson 1999). The "stress on stress response" (Viarengo et al. 1995), which consists in measuring the survival of mussels to air exposure, also represents a valuable and easy indicator of pollution-induced environmental stress but has never been applied to tropical species. The physiological response termed "Scope for Growth" (SFG) represents a more accurate and sensitive way of assessing the global health of green mussels (Widdows et al. 1995). SFG reflects the balance between processes of energy acquisition and expenditure providing information on the energy status of an organism. It has been demonstrated that the SFG technique, which is standardized and routinely applied in European monitoring programmes, could be readily applied to indigenous tropical bivalve species (Widdows et al. 1995).

Diseases

Diseases, partial mortality or bleaching are often related to environmental problems (Harvell et al. 1999) and could also be considered as generic biomarkers. Studies have been mostly conducted on biodiversity "key-species" that are essential contributors to the architectural, trophic and functional complexity of reef ecosystem.

Octocorallians and especially sea fans from temperate and tropical ecosystems are subject to several types of anthropogenic and natural stressors inducing damages on parts of or whole colonies. Effects include cortex injuries (necrosis) caused by deposits of algae or mucillaginous aggregates, boring species actions and pathogen infection due to dystrophic crisis (Smith et al. 1996; Nagelkerken et al. 1997). Unusual freshwater discharge, sedimentation and associated pollutants, mechanical impacts by fishing lines, nets, divers and anchors also count as major sources of perturbations (Perez et al. 2000). Data on incidence (i.e. percentage of colonies affected) and virulence (i.e. degree of mortality within each colony) are used to determine the extent of impact on sea-fan populations (Feral et al. 2003).

Scleractinian corals also present disease answer to particle, nutrient and metal inputs (Nugues 2002). Coral bleaching could be included as one form of disease but considering its essential linkage to global warming this topic is treated in other contributions to the present journal issue.

4 Indicators at organism to population levels

4.1 Indicators of particle inputs at organism to population levels

Scleractinian corals

Sedimentation and turbidity are known stressors for corals, and most studies have shown negative impacts of these factors at the colony, population, and community levels (Bak and Meesters 1999; Meesters et al. 2001). Sediment inputs reduce coral growth and calcification rates (Riegel et al. 1996), affect coral physiology and metabolism (Riegel and Branch 1995) and disturb reproductive patterns and settlement/recruitment processes (Gilmour 1999). As corals ability to adopt sediment resistant growth forms and sediment rejection behaviours vary from one species to another (Stafford-Smith 1993) particle inputs will cause changes in species composition and richness, living coral coverage, and other diversity indexes such as Shannon H' and Pielou J' (Adjeroud 1997; Brown et al. 2002). However, some studies have pointed out that corals were more resistant to sedimentation than expected, and that sedimentation/turbidity may have localized or negligible effects (McClanahan and Obura 1997). Recent studies even suggested that sediment could be a possible additional source of food for corals (Anthony 2000).

Corals are also sensitive to a variety of other environmental factors, and these factors can co-vary and have synergistic effects, so the descriptors presented above cannot be considered as specific indicators of particle inputs as a single source of perturbation (Edinger et al. 2000). Additional physiological studies on the response of coral species to sediment stress are necessary in order to identify more precisely sediment tolerant vs. sediment-intolerant species (McClanahan and Obura 1997).

4.2 Indicators of nutrient inputs at organism to population levels

Plankton

Phytoplankton populations are strongly related to water quality and provide early response to environmental stress and more specifically to changes in nutrient inputs. Plankton answers to nutrient inputs have been studied in temperate marine and estuarine systems and key species indicating eutrophication have even been identified (Livingston 2001). Plankton studies in coral reef lagoons are far less common and additional information will be generally required locally before associating phytoplankton to environmental surveys.

Natural factors such as the residence time of water significantly affect phytoplankton biomass and diversity even in pristine atoll lagoons (Delesalle and Sournia 1992) so strong differences naturally exist from one site to another. Furthermore, identifying environmental alteration as a function of biomass, diversity or production is not straightforward as gradients normally exist within a given system, especially where coral reef lagoons are bordering land masses. Such variability in nutrient and phytoplankton distribution can lead to conflicting interpretation (Kinsey 1991) but long term studies demonstrated the potential of simple parameters such as phytoplankton biomass to assess water quality degradation in coral reef lagoon systems (Weber and Weber 1998).

Phytoplankton production is the true biological answer to eutrophication but, thanks to its measurement easiness, biomass is often used as a substitute indicator of trophic status. Chlorophyll *a* and its by-products such as pheopigments may be considered as the most common parameters measured to assess phytoplankton biomass. In oligotrophic systems plankton primary producers present specific species composition with a dominance of small picoplankton cells (Charpy and Blanchot 1998; Delesalle et al. 2001). Anthropogenic inputs of nutrients and subsequent eutrophication will rapidly result in favouring the development of larger cells such as diatoms or dinoflagellates depending on silica limitation (Jacquet et al., in press). Therefore, detailed study of species composition or more simply of size class composition can be of great interest in surveying potential eutrophication effects.

Benthic algae

Coral reef algae are primary producers and inorganic nutrients evidently limit their development. Some evidence of a direct control of photosynthetic production and growth rates by inputs of inorganic nitrogen and phosphorus have been given (Lapointe 1997; Larned 1998) but recent works tend to question the direct relationship between nutrient and algal development due to the combined effect of additional factors (Mc Cook 1999). In the GBR, Sargassum growth was stimulated by nutrient additions but saturation occurred above a threshold corresponding to fringing reef concentrations (Schaffelke and Klumpp 1998) and cross-shelf differences in nutrient levels did not correlate with difference in Sargassum growth (Mc Cook 1999). The ENCORE experiment concluded to the lack of relationship between nutrient inputs and primary production or growth of the epilithic algal community (Larkum and Koop 1997). Other studies conducted at reef scale also demonstrated that algal communities from the Florida Keys were nutrient replete (Miller et al. 1999). During the last decade several studies tried to define nutrient concentration thresholds beyond which benthic algal blooms would occur (Lapointe 1997) but this concept is no longer accepted due to increasing acknowledgment of the strong diversity of coral reef community answers to strongly diverse ambient trophic conditions (Szmant 2001).

Certain algae such as *Enteromorpha* spp. (Fong et al. 1993) or *Dictyosphaeria cavernosa* (Stimson et al. 2001) have been reported to significantly develop in response to anthropogenic nutrient inputs. The foliose macroalgae *Sargassum* spp. is also known to have a high nutrient demand and to use a large range of nutrient sources (Schaffelke and Klump 1998; Schaffelke 2001). Such species with physiological capabilities to overgrow coral reefs in the presence of nutrient inputs can be considered as indicator of water quality. Conversely, nutrient may have deleterious effects on one of the more important group of reef algae such as crustose coralline algae (Fabricius and De'ath 2001) but opposite effects have also been reported (Smith et al. 2001).

Increase of tissue production (growth) rarely leads to the increase of the standing crop (tissue biomass, algal abundance) (Hatcher 1997). Accumulation of algal biomass only occurs when production exceeds total losses including herbivore grazing but increase in algal biomass has often been interpreted as a consequence of nutrient enhancement while it could result of reduced herbivore activity (Hughes et al. 1999). While most existing studies provide support for the importance of the herbivore activity in affecting algal cover, few of them demonstrate clearly the effect of nutrient enrichment at population or community levels. The overrun of benthic algal communities on coral reefs, is no longer widely interpreted as indicator of nutrient increase alone but rather as a consequence of a cascading of various factors (Mc Cook 1999; and Coral Reef 2001 special issue "Community dynamics and coral reef algae"). Even in well documented cases of anthropogenic eutrophication, nutrient increases are probably not the only cause of algal blooms (Cuet et al. 1988; Stimson et al. 2001). Therefore, evidence of direct nutrient effect on algal blooms is weak and there is scant evidence that algal cover may directly reflect nutrient inputs so benthic algae should be considered as non specific indicators of environmental alteration (see next section).

Scleractinian corals

A wide range of nutrient impacts have been reported, from little or no impacts to major changes in coral reef community structure (Naim 1993; Lapointe 1997; Koop et al. 2001; Szmant 2002). Some authors proposed threshold nutrient levels above which coral reefs would become degraded (Lapointe 1997) but the true magnitude and extent of the impacts of nutrient enrichment often depends on complex local factors (see previous section on Abiotic factors). Nutrient enrichment is generally considered to be mainly an indirect stress, as it first influences benthic and planktonic algae (Lapointe 1997). Elevated phytoplankton populations reduce light penetration which may in turn affect coral nutrition, growth, and survival (Kinsey and Davies 1979). Increased production in the water column often favours the growth of benthic filter-feeders which out compete corals for space (Birkeland 1977). As benthic algae increase in biomass, they colonize coral skeletons, overgrow living corals, and form thick mats which kill all underlying organisms by blocking light and trapping sediment (Mc Cook 1999; Mc Cook et al. 2001). Direct physiological effects of nutrient enrichment on growth, reproduction rate or settlement/recruitment rates have also been demonstrated for some coral species (Ferrier-Pagès et al. 2001; Harrison and Ward 2001; Cox and Ward 2002). Because algal blooms on coral reefs are generally controlled by a complex interactions of bottom-up (nutrient enrichment) and top-down (grazing) factors, caution have to be made when identifying which factors is responsible for the bloom (Hughes et al. 1999; Szmant 2002). It is also important to point out that an increase in nutrient level is not always associated with a decreased growth rate and increased mortality of coral colonies (Lough and Barnes 1997; Steven and Broadbent 1997).

Living coral coverage, sometimes associated with the ratio of living/dead coral coverage, or the ratio between algal/living coral coverage are the most commonly used descriptor of nutrient enrichment impact on coral populations. However, no detailed case-studies were conducted to validate the robustness and usefulness of these potential indicators. As for indicators of the sediment/turbidity stress, additional physiological studies on the response of coral species to nutrient stress are necessary in order to identify more precisely nutrient tolerant vs. nutrient-intolerant species.

4.3 Non specific bioindicators at organism to population levels

Bioindicators of multiple stresses at community level are presented and discussed in another article in the present journal issue and the following section focus on the way organisms and communities unspecifically respond to particle, nutrient and metal inputs.

Soft-bottom macrofauna

Sediment macrofauna communities integratively, orientedly and rapidly respond to various natural or human-induced disturbances even though they seldom discriminate between the true natures of the disturbance (Warwick 1993). The definition of numerical indices with well defined threshold values directly usable by stakeholders is generally inapplicable to macrobenthic indicator but large categories of environmental stress conditions, such as polluted, moderately polluted or unpolluted, can be defined (Warwick and Clarke 1993). Most concepts on macrobenthic indicators have been derived from studies of temperate ecosystems and applications to coral reef lagoons are scarce and a causal relationship may not automatically apply to different geographical areas (Keough and Quinn 1991).

Many taxa have been used as positive or negative indicators of anthropogenic inputs (Wilson and Jeffrey 1994). Polychaetes are globally considered as resistant to contaminants, followed by molluscs and crustaceans, echinoderms being considered as the most sensitive (Omori et al. 1994) but because Polychaetes are largely dominant and present a strong internal diversity in pollution sensitiveness it is a key taxa to marine environmental quality assessment (Pocklington and Wells 1992). Considering total macrobenthic community may prove uninformative so it is generally more effective to focus on phylum, family, genus or species levels and to work on high taxonomic levels (Olsgard et al. 1998). Among the wide range of diversity indices related (Warwick and Clarke 1995) very few have been used in tropical systems. Using such indices to identify anthropogenic impacts requires comparison between sites subject to contrasted disturbance conditions (Keough and Quinn 1991). The meta-analysis based on combined case studies of higher taxonomic levels to provide global insight on ecological functioning (Warwick and Clarke 1993) still has to be tested in different coral reef systems.

Production (P) is considered as a key integrative parameter of benthic ecosystem functioning (Warwick and Clarke 1993). When direct measurement is not available P may be assessed as $P = (\text{Biomass/Abundance})^{0.73}$ some adaptation in the exponent value being reported as a function of taxa or ecosystem. The trophic status also is an informative parameter, especially when considering polychaete populations (Frouin 2000), as a stressed system tend to have a simpler energy flow pathway than an unstressed one (Diaz 1992). In coral reefs, the lack of knowledge on species biology currently restrains those studies to systems rather than population level. At the system level, complex indicators such as the Sediment Quality Triad (Long and Chapman 1985), the Benthic Indices of Biotic Integrity (B-IBI) (Weisberg et al. 1997) or the EQUATION Index (Ferreira 2000) have been based on a combination of parameters dealing with sediment toxicity, chemistry and macrofauna community.

In conclusion, efficient benthic indicators should be based on higher taxonomic level and combine quantitative variables, preferentially biomass, with functional parameters such as trophic status and Jameson et al. (2001) recently proposed a framework for definition of such coral reefs multimetric indices. The following step now is to gather sufficient data to establish statistically and ecologically meaningful standardized numerical indices (Engle et al. 1994) usable on a local to regional basis.

Benthic algae

Previous section dealing with benthic algae and nutrient inputs demonstrated the complexity of the relationship between different sources of stress and shifts in benthic algal community structure (Hughes et al. 1999; Mc Cook 1999). On Hawaiian reefs with low natural algal cover and reduced fishing pressure, algal abundance and community composition (coralline crust algae vs. fleshier groups) were controlled by a combination of bottom-up (nutrient inputs) and top-down factors (grazing pressure) (Smith et al. 2001). Moreover, the combined actions of nutrient inputs, increased turbidity, competition with introduced species, or herbivores grazing are synergistic and may result in alteration of algae population as demonstrated by the recent overgrowth of Dictyosphaeria in some parts of the Kaneohe Bay (Stimson et al. 2001).

Several environmental factors changed the dynamics of coral reef algal communities since the middle of the past century and led to dramatic phase shifts from coral-dominated to algal-dominated coral reefs. The lack of reliable macroalgae indicators of nutrient levels and our own expertise lead to recommend the use of benthic algae as non specific bioindicators. Temporal and spatial surveys should be simultaneously conducted on impacted and non impacted control sites using parameters on the diversity and abundance of algal cover vs. coral cover, with special attention to large brown algae (e.g. as *Sargassum* spp., Dictyotales), crusting coralline algae (CCA), and opportunistic species such as green algae (e.g. *Enteromorpha*/*Ulva* complex), or cyanobacteria.

Sponges

Sponges have some interesting potential as bioindicators of environmental conditions in marine ecosystems (Perez 2000). Sponge communities or species proved to be very sensitive to environmental crises in temperate as well as in tropical ecosystems (Alcolado 1994; Holmes et al. 2000). It has been demonstrated that inputs of inorganic and organic nutrients (natural or anthropogenic) stimulate sponge dominance in coral reef systems (Wilkinson and Cheshire 1990) but combined inputs of nutrients and suspended particles have been identified as the key factor allowing for sponges to outgrow algae (Zea 1994). Clionid sponges (Demospongiae, Clionidae), well known for their bioeroding activity on corals (Schönberg and Wilkinson 2001), are considered as the taxa with highest bioindicative potential. Carbonate boring clionid sponges living in symbiosis with zooxanthellae are "r" strategy opportunist species and under special environmental conditions they may develop as encrusting or massive form after extensive bioerosion of the calcareous substratum. Tropical bioeroding sponges have been used to reveal the combined effects of particle and nutrient inputs on Caribbean reefs (Holmes 2000), Indian Ocean (Cuet et al. 1988) and Pacific reefs (Holmes et al. 2000). Bioindicators related to coral reef sponges are summarized (Table 3).

Scleractinian corals

Species or generic richness, species diversity and rarity indexes, density/abundance of colonies, living coral coverage, living/dead coral coverage, or algal/coral coverage rank as the most common indicators used to detect changes in coral reef "health" (Done 1995; DeVantier et al. 1998). Many descriptors or multimetric indexes have also been proposed as indicators of coral reef 'health' (references, Table 3). Even coral bleaching may be a consequence of anthropogenic inputs of particle, nutrient and metals (Jones 1997) but considering its major linkage to global warming bleaching is discussed in another part of this journal issue.

Critical analysis of published and unpublished information demonstrated that instead of targeting a single indicator it was necessary to combine three different and complementary indicators: one indicating the diversity of the area (for corals, the generic richness is sufficient), one estimating the abundance/biomass (density of colonies and/or living coral coverage for example), and one estimating the potential for recovery (by studying the density of recruits/juveniles). Information on recruitment patterns is essential because recolonization after a perturbation directly depends on the number of potential colonizers (Done 1995) and because recruits or juveniles are usually more sensitive to pollution than adults (Wittenberg and Hunte 1992). Information from those three indicators could further be merged to calculate a multimetric integrative index making intercomparison of coral reef "health" assessments easier.

Additionally, remote sensing applications have been increasingly directed toward the characterization and survey of coral reef evolution due to a combination of anthropogenic influences including particle, nutrient and metal inputs (Andréfouët et al. 2003). The use of this technique yielding large scale environmental assessment is further discussed in the present journal issue but its potential as an indicator of particle, nutrient and metal inputs, combined or single, has to be underlined.

Fishes

There has been surprisingly little work on the effects of anthropogenic inputs on coral reef fishes. Fishes are interesting candidates as bio-indicators (Karr et al. 1986; Barbour et al. 1999), as they are long-lived (integration of disturbance long-term effects) and easy to sample. One major drawback is that fish are expected to integrate the cumulative effects of multiple stressors (Ganasan and Hughes 1998) and it may be difficult to identify the real cause of an observed pattern, especially on coral reefs subject to various disturbances (Jones and Syms 1998; Chabanet et al. 2005). A second limitation to the use of fishes as indicators arises from their mobility hence the need to select relatively sedentary reef fish species. Coral reef fishes are very diverse either in term of taxonomic composition, behaviour or life history traits hence providing structural and functional bioindicative responses. Many reef fishes specialise on one narrow type of food, and for example predator of sessile invertebrates may be particularly sensitive indicators of pollution since their prey bioaccumulate pollutants. Structural and functional indicators may further have different ecological significances when considered at population or community levels.

At *population-level*, disturbances are expected to cause changes in fish density, biomass or size distribution. It has been demonstrated that the abundance of parasite feeders (cleaner fish) increased in some polluted sites as anthropogenic inputs favoured parasites (Grutter 1997). It was also suggested that decrease in the distribution of strict coral feeders, such as butterflyfishes (Chaetodontidae), could reveal sub-lethal stress on corals (Hourigan et al. 1988; Crosby and Reese 1996) but in spite of numerous studies (Chabanet et al. 2005) such a relationship has not be clearly established (Erdmann 1997; Jameson et al. 1998). One may also expect changes in sex ratios, behaviour, growth, and mortality rates. Many fish species (e.g., Labridae and Scaridae) are haremic and change from female in their first life stages to more brightly coloured dominant males when their age, size or social organisation increase. Anthropogenic inputs may affect their growth and consecutively their sexual organisation (e.g., earlier sex reversal, lower sex ratio). Changes in the feeding or social behaviour may also occur for some species, such as corallivorous butterflyfishes (Crosby and Reese 1996) a change in coral preferences or feeding rates being indicative of coral stress. Some territorial damselfishes (Pomacentridae) "cultivate" a patch of turf algae, excluding all other herbivorous fish from that area and growth, density, or size distribution of these species may be modified in response to the enhanced growth of such algae patches due to nutrient inputs (Chabanet 1994). Other grazing fish however respond in different ways to eutrophication (Koop et al. 2001).

At the *community-level*, studies are more numerous but still insufficient to allow for reliable generalizations. Some authors mentioned the probable role of terrestrial runoff gradients for explaining the diversity and abundance of reef fish communities (Williams and Hatcher 1983; Russ 1984), but none provided a clear quantification of this influence. Letourneur et al. (1998) and Grimaud and Kulbicki (1998) observed that diversity, abundance, and biomass of commercial reef fishes were correlated with a decreasing terrestrial influence. Considering ground discharge, some studies showed a significant decrease in total fish abundance (Harmelin-Vivien 1992; Chabanet et al. 1995; Khalaf and Kochzius 2002) when others observed an opposite trend (Grigg 1994; Letourneur et al. 1999; Bozec et al. 2005). In most of these studies the number of fish species has proved to be an inappropriate indicator of anthropogenic inputs, except for Harmelin-Vivien (1992) who observed a decrease in species richness due to the magnitude and duration of stress. The fish trophic structure seems to be more sensitive, as increases in abundance of herbivores and detritivores (Khalaf and Kochzius 2002) or plankton and suspended-particle feeders (Grigg 1994; Bozec et al. 2005) were observed sometimes above the system carrying capacity as a result of water enrichment by organic matter.

Parasites

The intimate relationship between parasites and their hosts as well as their great species richness and life cycle diversity, has lead people to consider parasites as biological indicators for many years (see reviews in Overstreet 1997; Marcogliese and Cone 1997). Parasite populations can either increase or decrease when facing environmental changes depending on their life cycle and the nature of the environmental change. They can either be used at a spatial or temporal scale, and quantitatively (variation of the number of parasite counted within one host species) or qualitatively (variation in the species richness or in the parasite community structure).

Macro parasites may have a simple life cycle using one single host or a complex life cycle requesting several host species. Simple life cycle parasites such as monogeneans and crustaceans are mostly external parasites in direct contact with the fish environment and water conditions may considerably influence the survival or the proliferation of such parasites. They also are much more host specific, i.e. one parasite species can only be found on one host species, hence more sensitive to changes in environmental conditions. Environmental stressors, such as wastewater or industrial pollutants can result in an increase in fish parasites due to a decrease in immunological defences and a lesser resistance to infections (Steedman 1991; MacKenzie et al. 1995).

Macro parasites with complex life cycles depend on the presence of intermediate hosts to complete their life cycle and to survive locally. Consequently, they strongly reflect the local disappearance of one species potentially revealing more chronic problems within the studied ecosystem. Some works reported that pollution correlated with the decrease in abundance and prevalence of complex life-cycle parasite species, most certainly due to the disappearance of one of the intermediate hosts (MacKenzie et al. 1995).

Finally, micro parasites such as Trichodinid appeared to be consistently associated with host stress induced by water conditions (Lafferty 1997) but they are much more difficult to use in routine surveys.

One of the major points in using parasites as biological indicators is related to the complexity of their systematic. New species are often discovered when considering regions or host species that were not previously studied for parasitological purposes. These problems could be partially solved by using the whole parasite community as a bioindicator.

5 Conclusion

Considering the spreading and accelerating degradation of coral reefs and coral reef lagoons a more extensive use of carefully selected indicators of environmental status is strongly needed and represents a major challenge for the new century. This paper provides synthetic information on existing indicators and their validation in coral reef lagoon environments and investigates some promising ongoing research tracks that should provide new and efficient environmental monitoring tools in the near future.

Coral reef lagoons are very complex and variable ecosystems and their structure and functioning may significantly differ from one site to another. Therefore, environmental monitoring requires significant adaptation to the local specificities of each considered system and it is absolutely necessary to identify indicators and define indicator responses specifically adapted to local environmental conditions. Fixing the limits within which a specific or a generic indicator may reveal various levels of environmental degradation is an essential step that will generally require onsite adaptation and environmental managers must be fully aware of this essential need to locally validate and calibrate indicators. This review also stressed that proper environmental surveys could not rely on a single indicator but that selecting a combination of adapted indicators was an essential step to obtain relevant information. Combining non specific bioindicators of ecosystem degradation with abiotic indicators specifically identifying the sources of perturbation further appeared as necessary to the selection of adapted environmental management actions.

Unfortunately, this review also clearly demonstrated that the present scientific background still is largely insufficient to propose unambiguous indicators in answer to all the complex environmental issues arousing in the tropical coastal zone. Our knowledge on environmental indicators in tropical systems is largely deficient when compared with the existing scientific background in temperate systems demonstrating that much more scientific work is required. Combined fundamental and applied research is necessary and the constant pressure from environmental manager to obtain cost-effective indicators is obviously a major force driving science to environmental application. Considering the considerable economic investment that has been devoted to development and the global awareness regarding coral reef environmental status worldwide the present level of scientific and technical ignorance is unacceptable and a significant reinforcement in environmental sciences is an absolute prerequisite to the true achievement of environmental management.

Acknowledgements. This review was initiated from a workshop organized in New Caledonia with the support of the French "Programme National Environnement Côtier" (PNEC), L'Institut de Recherche pour le Développement (IRD) and the Secretariat of the Pacific Commission (SPC).

References

Adjeroud M., 1997, Factors influencing spatial patterns on coral reefs around Moorea, French Polynesia. Mar. Ecol. Prog. Ser. 159, 105-119.

Adjeroud M., 2000, Zonation des communautés macrobenthiques le long de deux baies d'un écosystème corallien insulaire (Moorea, Polynésie Française). C. R. Acad. Sci. Ser. III, Sciences de la vie 323, 305-313.

Alcolado P.M., 1994, General trends in coral reef sponge communities of Cuba. In: Van Soest R.W.M., Van Kempen T.M.G., Braekman J.C. (Eds.), Sponges in time and space; Biology, Chemistry, Paleontology. A.A. Balkema, Rotterdam, pp. 251-255.

Andréfouët S., Kramer P., Torres-Pulliza D., Joyce K.E., Hotchberg E.J., Garza-Pérez R., Mumby P.J., Riegl B., Yamano H., White W.H., Zubia M., Brock J.C., Phinn S.R., Naseer A., Hatcher B.G., Muller-Karger F.E., Multisite evaluation of IKONOS data for classification of tropical coral reef environments. Remote Sensing Environ 88, 128-143.

Anthony K.R.N., 2000, Enhanced particle-feeding capacity of coral on turbid reefs (Great Barrier Reef, Australia). Coral Reefs 19, 59-67.

Asper V. L., 1987, A review of sediment trap technique. J. Mar. Tech. Soc. 21, 18-25.

Atkinson M.J., Carlson B, Crow GL, 1995, Coral growth in high nutrient, low-pH seawater: A case study of corals cultured at the Waikiki Aquarium, Honolulu, Hawaii. Coral Reefs 14, 215-233.

Bak R.P.M., Meesters E.H., 1999, Population structure as a response of coral communities to global change. Am. Zool. 39, 56-65.

Barbour M.T., Gerritsen J., Snyder B.D., Stribling J.B., 1999, Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Barnes D.J., Lough J.M., 1999, Porites growth characteristics in a changed environment: Misima Island, Papua New Guinea. Coral Reefs 18, 213-218.

Barnes DJ, Lough JM, 1992, Systematic variations in the depth of skeleton occupied by coral tissue in massive colonies of *Porites* from the Great Barrier Reef. J. Exp. Mar. Biol. Ecol. 159, 113-128.

Bastidas C., Bone D., Garcia E.M., 1999, Sedimentation rates and metal content of sediments in a Venezuelan coral reef. Mar. Pollut. Bull. 36, 16-24.

Bastidas C., Garcia E., 1999, Metal content on the reef coral Porites astroides: An evaluation of river influence and 35 years of chronology. Mar. Pollut. Bull. 38, 899-907.

Birkeland C, 1977, The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. In: Proceedings from the 3rd International Coral Reef Symposium 1, pp. 15-21.

Blanchot J., Charpy L., Le Borgne R., 1989, Size composition of particulate organic matter in hte lagoon of Tikehau atoll (Tuamotu archipelago). Mar. Biol. 102, 329-339.

Bourdelin F., 1994, Biologie et écophysiologie de deux populations de Modiolus auriculatus Krauss (Mytilidae) de Tahiti : Application à l'étude des pollutions chimiques des milieux lagonaires. Thèse de Doctorat, Université Française du Pacifique, Tahiti.

Bourdelin F., 1996, Physiological responses of the tropical mussel, Modiolus auriculatus – A possible biological monitor in French Polynesia. Mar. Pollut. Bull. 32, 480-485.

Bouvet G., Ferraris J., Andréfouët S., 2003, Evaluation of large-scale unsupervised classification of New Caledonia reef ecosystems using Landsat 7 ETM+ imagery. Oceanol. Acta 26, 281–290.

Bozec Y.-M., Kulbicki M., Chassot E., Gascuel D., 2005, Trophic signature of coral reef fish assemblages: Towards a potential indicator of ecosystem disturbance. Aquat. Living Resour. 18, 103-109.

Breau L., 2003, Étude de la bioaccumulation des métaux dans quelques espèces marines tropicales : recherche de bioindicateurs de contamination et application à la surveillance de l'environnement côtier dans le lagon sud-ouest de la Nouvelle-Calédonie. Thèse de Doctorat, Université de La Rochelle, La Rochelle.

Brown B.E., Clarke K.R., Warwick R.M., 2002, Serial patterns of biodiversity change in corals across shallow reef flats in Ko Phuket, Thailand, due to the effects of local (sedimentation) and regional (climatic) perturbations. Mar. Biol. 141, 21-29.

Brunskill G.J., Zagorskis I., Pfitzner J., 2002, Carbon Burial Rates in Sediments and a Carbon Mass Balance for the Herbert River Region of the Great Barrier Reef Continental Shelf, North Queensland, Australia, Estuar. Coast. Shelf Sci. 54, 677-700.

Castro N.G., 2001, Monitoring ecological and socioeconomic indicators for coral reef management in Colombia. Bull. Mar. Sci. 69, 847-859.

Chabanet P., 1994, Étude des relations entre les peuplements benthiques et les peuplements ichtyologiques sur le complexe récifal de St.Gilles/la Saline- Ile de La Réunion. Thèse de Doctorat, Université de Perpignan, Perpignan.

Chabanet P., Dufour V., Galzin R., 1995, Disturbance impact on reef fish communities in Reunion Island (Indian Ocean). J. Exp. Mar. Biol. Ecol. 188, 29-48.

Chabanet, P., Adjeroud, M., Andrefouët, S., Bozec, Y.-M., Ferraris, J., Garcìa-Charton, J., Schrimm, M., 2005, Human induced physical disturbances and their indicators on coral reef habitats: A multiscale approach. Aquat. Living Resour. 18.

Charpy L., Phytoplankton biomass and production in two Tuamotu atoll lagoons (French Polynesia). Mar. Ecol. Progr. Ser. 145, 133-142.

Charpy L., Blanchot J., 1998, Photosynthetic picoplankton in French Polynesian atoll lagoons: Experimentation of taxa contribution to biomass and production by flow cytometry. Mar. Ecol. Progr. Ser. 162, 57-70.

Charpy L.C., Charpy-Roubaud C.J., 1991, Particulate organic matter fluxes in a Tuamotu atoll lagoon (French Polynesia). Mar. Ecol. Progr. Ser. 71, 53-63.

Charpy L., Dufour P., Garcia N., 1997, Particulate organic matter in sixteen Tuamotu atoll lagoons (French Polynesia). Mar. Ecol. Progr. Ser. 151, 55-65.

Charpy-Roubaud C, Charpy L, Sarazin G., 1996, Diffusional nutrient fluxes at the sedimentwater interface and organic matter mineralization in an atoll lagoon (Tikehau, Tuamoto Archipelago, French Polynesia). Mar. Ecol. Prog. Ser. 132, 181–190.

Cheung V.V., Wedderburn R.J., Depledge M.H. 1998, Molluscan lysosomal responses as a diagnostic tool for the detection of a pollution gradient in Tolo Harbour, Hong Kong. Mar. Environ. Res. 46, 237-241.

Cheung Y.H., Wong M.H., 1997, Depuration and bioaccumulation of heavy metals by clams from Tolo Harbour, Hong Kong. Toxicol. Environ Manage. 16, 743-751.

Chevillon C., 1992, Biosédimentologie du Grand Lagon Nord de la Nouvelle Calédonie. Études et Thèses, Editions ORSTOM, IRD, Paris.

Chevillon C., 1996, Skeletal composition of lagoonal modern sediments in New Caledonia: Coral, a minor constituent. Coral Reefs 15, 199-207.

Clavier J., Chardy P., Chevillon C., 1995, Sedimentation of particulate matter in the south-west lagoon of New Caledonia; spatial and temporal patterns. Estuar. Coast. Shelf Sci. 40, 281-294

Clavier J., Garrigue C., 1999, Annual sediment primary production and respiration in a large coral reef lagoon (SW New Caledonia). Mar. Ecol. Progr. Ser. 191, 79-89.

Clavier J., Boucher G., Chauvaud L., Fichez R. Chifflet S., 2005, Benthic response to ammonium pulses in a tropical lagoon. Implications for coastal environment functioning. J. Exp. Mar. Biol. Ecol. 316, 231-241.

Cox EF, Ward S, 2002, Impact of elevated ammonium on reproduction in two Hawaiian scleractinian corals with different life history patterns. Mar. Pollut. Bull. 44, 1230-1235.

Cribb T.H., Pichelin S., Dufour V., Bray R.A., Chauvet C., Faliex E., Galzin R., Lo C.M., Yat A.-L., Morand S., Rigby M.C., Sasal P., 2000, Parasites of recruiting coral reef fish larvae in New Caledonia. Int. J. Parasitol. 30, 1445-1451.

Crosby M.P., Reese E.S., 1996, A manual for monitoring coral reefs with indicator species: Butterflyfishes as indicators of change on Indo-Pacific reefs. Office of Ocean and Coastal Resource Management, NOAA. Silver Spring, MD.

Cuet P., Naim O., Faure G., Conan J.-Y. 1988, Nutrient-rich groundwater impact on benthic communities of La Saline fringing reef (Reunion Island, Indian Ocean): Preliminary results. Proc. 6th Int. Coral Reef Symp. 2, 207-212.

David C.P., 2002, Heavy metal concentrations in marine sediments impacted by a mine-tailings spill, Marinduque Island, Philippines. Environ. Geol. 42, 955-965.

David C.P., 2003, Heavy metal concentrations in growth bands of corals: A record of mine tailings input through time (Marinduque Island, Philippines). Mar. Pollut. Bull. 46, 187-196.

Delesalle B., Pichon, M., Frankignoulle M., Gattuso J.P., 1993, Effects of a cyclone on coral reef phytplankton biomass, primary production and composition (Moorea Island, French Polynesia). J. Plankton Res. 15, 1413-1423.

Delesalle B., Sakka A., Legendre L., Pagès J., Charpy L., Loret P., 2001, The phytoplankton of Takapoto Atoll (Tuamotu Archipelago, French Polynesia): Time and space variability of biomass, primary production and composition over 24 years, Aquat. Living Resour. 14, 175-182.

Delesalle B., Sournia A., 1992, Residence time of water and phytoplankton biomass in coral reef lagoons. Cont. Shelf Res. 12, 939-949

Denton G.R.W., Burdon-Jones C., 1986a, Trace metals in algae from the Great Barrier Reef. Mar. Pollut. Bull. 17, 98-107.

DeVantier L.M., De'ath G., Done T.J., Turak E., 1998, Ecological assessment of a complex natural system: A case study from the Great Barrier Reef. Ecol. Appl. 8, 480-496.

Diaz R. J. 1992, Ecosystem assessment using estuarine and marine benthic community structure. Lewis Publishers Inc.

Done T.J., 1995, Ecological criteria for evaluating coral reefs and their implications for managers and researchers. Coral Reefs 14, 183-192.

Downs C.A., Mueller E., Phillips S., Fauth J.E., Woodley C.M., 2000, A molecular biomarker system for assessing the health of coral (*Monstastraea faveolata*) during heat stress. Mar. Biotechnol. 2, 533-544.

Edinger E.N., Limmon G.V., Jompa J., Widjatmoko W., Heikoop J.M., Risk M.J., 2000, Normal coral growth rates on dying reefs: Are coral growth rates good indicators of reef health? Mar. Pollut. Bull. 40, 404-425.

Edinger E.N., Risk M.J., 1999, Coral morphology triangles indicate conservation value for coral reef assessment and management. Biol. Conserv. 92, 1-13.

Elfwing T., Blidberg E., Sison M., Tedengren M., 2003, A comparison between sites of growth, physiological performances and stress responses in transplanted *Tridacna gigas*. Aquaculture 219, 815-828.

Engle V.D., Summers J.K., Gaston G.R., 1994, A benthic index of environmental condition of Gulf of Mexico estuaries. Estuaries 17, 372-384.

English S., Wilkinson C., Baker V., 1997, Survey manual for tropical marine resources. Australian Institute of Marine Science, Townsville, Australia.

Erdman M., 1997, Butterflyfish as bioindicators – a review. Reef Encounter. 21, 7-9.

Esslemont G., 2000, Heavy metals in seawater, marine sediments and corals from the Townsville section, Great Barrier Reef Marine Park, Queensland. Mar. Chem. 71, 215-231.

Fabricius K., De'ath G., 2001, Environmental factors asociated with the spatial distribution of crustose coralline algae on the Great barrier Reef. Coral Reefs 19, 303-309.

Fallon S.J., White J.C., McCulloch M.T., 2002, Porites corals as recorders of mining and environmental impacts: Misima Island, Papua New Guinea. Geochim. Cosmochim. Acta 66, 45-62.

Fang L.S., Chen Y.W.J., Soong K.Y., 1987, Methodology and measurement of ATP in coral. Bull. Mar. Sci. 41, 605-610.

Féral J.P., Fourt M., Perez T., Warwick R., Emblow C., Hummel H., Van Avesaath P., Heip C., 2003, European Marine Biodiversity Indicators. Booklet N°2 of the Biomare Programme Implementation and Networking of Large Scale and Long Term Marine Biodiversity Research in Europe.

Fernandez J.-M., Moreton B., Fichez R., Breau L., Magand O., Badie C., 2002, Advantages of combining ^{210}Pb and geochemical signature determinations in sediment record studies; application to coral reef lagoon environments. In: Fernandez J.-M., Fichez R. (Eds.), Environmental changes and radioactive tracers, IRD Editions, Paris, pp. 187-199.

Ferreira J.G., 2000, Development of an estuarine quality index based on key physical and biogeochemical features. Ocean Coast. Manage. 43, 99-122.

Ferrier-Pagès C, Schloelzke V, Jaubert J, Muscatine L, Hoegh-Guldberg O, 2001, Response of a scleractinian coral, *Stylophora pistillata*, to iron and nitrate enrichment. J. Exp. Mar. Biol. Ecol. 259, 249-261

Fichez R., Harris P., Fernandez J.M., Chevillon C., Badie C., 2005, Sediment records of past anthropogenic environmental changes in a barrier reef lagoon (Papeete, Tahiti, French Polynesia). Mar. Pollut. Bull. 50, 599-608.

Flammang P., Warnau M., Temara A., Lane D.J.W., Jangoux M., 1997, Heavy metals in Diadema setosum (Echinodermata, Echinoidea) from Singapore coral reefs. J. Sea Res. 38, 35-45.

Fones G.R., Davison W., Holby O., Jorgensen B.B., Thamdrup B., 2001, High-resolution metal gradients measured by in situ DGT/DET deployment in Black Sea sediments using an autonomous benthic lander. Limnol. Oceanogr. 46, 982-988.

Fong P, Donohoe R.M., Zedler J.B., 1993, Competition with macroalgae and benthic cyanobacterial mats limits phytoplankton abundance in experimental microcosm. Mar. Ecol. Progr. Ser. 100, 97-102.

Frouin P., 2000, Effects of anthropogenic disturbances of tropical soft-bottom benthic communities. Mar. Ecol. Progr. Ser. 194, 39-53.

Frouin P., Hutchings, P., 2001, Macrobenthic communities in a tropical lagoon (Tahiti, French Polynesia, Central Pacific). Coral Reefs 19, 277-285.

Furnas M.J., Mitchell A.W., Revelante N., 1990, Phytoplankton biomass, primary production in semi-enclosed reef lagoons of the central Great Barrier Reef. Coral Reefs 9, 1-10.

Gaccia V.G., Millero F.J., Palanques A., 2003, The distribution of trace metals in Florida Bay sediments. Mar. Pollut. Bull. 46, 1420-1433.

Ganasan V., Hughes R.M., 1998, Application of an Index of Biological Integrity (IBI) to fish assemblages of the Rivers Khan and Kshipra (Madhya Pradesh), India Freshwater Biol. 40, 367-383.

Gardner W.D., 2000, Sediment trap sampling in surface waters. In: Hanson R.B., Ducklow H.W., Field J.G. (Eds.), The Changing Ocean Carbon Cycle: A midterm synthesis of the Joint Global Ocean Flux Study, Cambridge University Press, Cambridge, UK, pp. 240-281.

Garzon-Ferreira J., Zea S., Diaz J.M., 2005, Incidence of partial mortality and other health indicators in hard coral communities of four southwestern Caribbean atolls. Bull. Mar. Sci. 76, 105-122.

Gilmour J., 1999, Experimental investigation into the effects of suspended sediment on fertilisation, larval survival and settlement in a scleractinian coral. Mar. Biol. 135, 451-462.

Ginsburg R.N., Bak R.P.M., Kiene W.E., Gischler E., Kosmynin V., 1996, Rapid assessment of reef condition using coral vitality. Reef Encounter. 19, 12-14.

Glynn P.W., Szmant A.M., Corcoran E.F., Cofer-Shabica S.V., 1989, Condition of coral reef cnidarians from the northern Florida reef tract: Pesticides, heavy metals, and histopathological examination. Mar. Pollut. Bull. 20, 568-576.

Gomez E.D., Alino P.M., Yap H.T., Licuanan, W.Y., 1994, A review of the status of Phillipine reefs. Mar. Pollut. Bull. 29, 62-68.

Grenz C., Denis L., Boucher G., Chauvaud L. Clavier J., Fichez R., Pringault O., 2003, Spatial variability in sediment oxygen consumption under winter conditions in a lagoonal system in New Caledonia (South Pacific). J. Mar. Biol. Ecol. 285-286, 33-47.

Grice A.M., Loneragan N.R., Dennison W.C., 1996, Light intensity and the interactions between physiology, morphology and stable isotope ratios in five species of seagrass. J. Exp. Mar. Biol. Ecol. 195, 91-110.

Grigg R.W., 1994, Effects of sewage discharge, fishing pressure and habitat complexity on coral ecosystems and reef fishes in Hawaii. Mar. Ecol. Progr. Ser. 103, 25-34.

Grimaud J., Kulbicki M., 1998, Influence de la distance à l'océan sur les peuplements ichtyologiques des récifs frangeants de Nouvelle-Calédonie, C.-R. Acad. Sci. Paris 321, 923-931.

Grutter A.S., 1997, Spatiotemporal variation and feeding selectivity in the diet of the cleaner fish *Labroides dimidiatus*. Copeia 2, 346-355.

Guzman H.M., Burns K.A., Jackson J.B.C., 1994, Injury, regeneration and growth of Caribbean reef corals after a major oil spill in Panama. Mar. Ecol. Prog. Ser. 105, 231-241

Hamilton L.J., Mulhearn P.J., Poeckert R., 1999, Comparison of RoxAnn and QTC-View acoustic bottom classification system performance for the Cairns area, Great Barrier Reef, Australia. Cont. Shelf Res. 19, 1577-1597.

Hanna R.G., Muir G.L., 1990, Red Sea corals as biomonitors of trace metal pollution. Environ. Monit. Assess. 14, 211-222.

Harmelin-Vivien M.L., 1992, Impact of human activities on coral reef fish communities in French Polynesia. Cybium 16, 279-289.

Harriott V.J., 1993, Coral lipids and environmental stress. Environ. Monit. Assess. 25, 131-139.

Harris P., 1998, Modifications des caractéristiques chimiques du lagon de Papeete liées à l'activité humaine : Intérêt des traceurs sédimentaires géochimiques et biogéochimiques dans la reconstitution de l'évolution de l'environnement au cours des 150 dernières années. Thèse de Doctorat, Université Française du Pacifique, Papeete, Tahiti.

Harrison P.L., Ward S., 2001, Elevated levels of nitrogen and phosphorus reduce fertilisation success of gametes from scleractinian reef corals. Mar. Biol. 139, 1057-1068.

Harvell C.D., Kim K., Burkholder J.M., Colwell R.R., Epstein P.R., Grimes D.J., Hofmann E.E., Lipp, E.K., Osterhaus A.D.M.E., Overstreet R.M., Porter J.W., Smith G.W., Vasta G.R., 1999, Emerging marine diseases - Climate links and anthropogenic factors. Science 285, 1505-1510.

Hata H., Kudo S., Yamano H., Kurano N., Kayann H., 2002, Organic carbon flux in Shiraho reef (Ishigaki Island, Japan). Mar. Ecol. Prog. Ser. 232, 129-140.

Hatcher B.G., 1997, Organic production and decomposition. In: Birkeland C. (Ed.), Life and death of coral reefs. Chapman and Hall, New York, pp. 140-174.

Haynes D., Johnson J.E., 2000, Organochlorine, heavy metal and polyaromatic hydrocarbon pollutant concentrations inn the Great Barrier Reef (Australia) environment: A review. Mar. Pollut. Bull. 41, 267-278.

Haynes D., Kwan D., 2002, Trace metals in sediments from Torres Strait and the Gulf of Papua: Concentrations and water circulation patterns. Mar. Pollut. Bull. 44, 1296-1313.

Heikoop J.M., Risk M.J., Lazier A.V., Edinger E.N., Jompa J., Limmon G.V., Dunn J.J., Browne D.R., Schwarcz H.P., 2000, Nitrogen-15 signals of anthropogenic nutrient loading in reef corals. Mar. Pollut. Bull. 40, 628-636.

Hodgson G., 1999, A global assessment of human effects on coral reefs. Mar. Pollut. Bull. 38, 345-355.

Holmes K.E., 2000, Effects of eutrophication on bioeroding sponge communities with the description of new West Indian sponges, *Cliona* spp. (Porifera: Hadromerida: Clionidae). Invertebr. Biol. 119, 125-138.

Holmes K.E., Edinger E.N., Hariyadi Limmon G.V., Risk M.J., 2000 Bioerosion of live massive corals and branching coral rubble on Indonesian coral reefs. Mar. Pollut. Bull. 40, 606-617.

Holmes R.M., Aminot A., Kérouel R., Bethanie A., Hooher A., Peterson B.J., 1999, A simple and precise method for measuring ammonium in marine and freshwater ecosystems. Can. J. Fish. Aquat. Sci. 56, 1801-1808.

Horrocks J.L., Steward G.R., Dennison W.C., 1995, Tissue nutrient content of *Gracilaria* spp. (Rhodophyta) and water quality along an estuarine gradient. Mar. Freshwater Res. 46, 975-983.

Hourigan T.F., Tricas T.C., Reese E.S., 1988, Coral Reef Fishes as Indicators of Environmental Stress in Coral Reefs. In: Soule, DF, Kleppel, GS (Eds.), Marine Organisms as Indicators. Springer-Verlag, New York.

Hughes G., 2002, Environmental indicators. Ann. Tourism Res. 29, 457-477.

Hughes T.P., Szmant A.M., Steneck R., Carpenter R., Miller, S, 1999, Algal blooms on coral reefs: what are the causes? Limnol. Oceanogr. 44, 1583-1586.

Hung T.-C., Meng P.-J., Han B.-C., Chuang A., Huang C.-C., 2001, Trace metals in different species of mollusca, water and sediments from Taiwan coastal area. Chemosphere 44, 833-841.

Hutchings P.A., Peyrot-Clausade M., 2002, The distribution and abundance of boring species of polychaetes and sipunculians in coral substrates in French Polynesia. J. Exp. Mar. Biol. Ecol. 269, 101-121.

Inoue M., Suzuki A., Nohara M., Kan H., Edward A., Kawahata H., 2004, Coral skeletal tin and copper concentrations at Pohnpei, Micronesia: Possible index for marine pollution by toxic antibiofouling paints. Environ. Pollut. 129, 399-407.

Jacquet S., Delesalle B., Torréton J.-P., Blanchot J., 2005, Spatial phytoplankton composition in relation to eutrophication in the SW lagoon of New-Caledonia. Mar. Ecol. Progr. Ser., in press.

Jaffé R., Fernandez A., Alvaro J., 1992, Trace metal analyses in octocorals by microwave acid digestion and graphite furnace atomic-absorption spectrometry. Talanta 39, 113-117.

Jaffé R., Leal I., Alvarado J., Gardinali P.R., Sericano J.L., 1998, Baseline study on the levels of organic pollutants and heavy metals in bivalves from the Morrocoy National Park, Venezuela. Mar. Pollut. Bull. 36, 925-929.

Jameson S.C., Erdmann M.V., Gibson, G.R., Potts K.W., 1998, Development of biological criteria for coral reef ecosystem assessment, USEPA, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC.

Jameson S.C., Erdmann M.V., Karr J.R., Potts K.W., 2001, Charting a course toward diagnostic monitoring: A continuing review of coral reef attributes and a research strategy for creating coral reef indexes of biotic integrity. Bull. Mar. Sci. 69, 701-744.

Jones R.J., 1997, Zooxanthellae loss as a bioassay for assessing stress in corals. Mar. Ecol. Progr. Ser. 149, 163-171.

Jones G.P., Syms C., 1998, Disturbance, habitat structure and the ecology of fishes on coral reefs. Aus. J. Ecol. 23, 287-297.

Kaiser J., Klanning, J.E., and Erickson L.E., 2001, Bioindicators and Biomarkers of Environmental Pollution and Risk Assessment. Science Publishers Inc., Plymouth, UK.

Karr, J.R., Fausch K.D., Angermeier P.L., Yant P.R., Schlosser I.J., 1986, Assessing biological integrity in running waters, a method and its rational. Illinois Natural History Survey, Spec. Publ. 5.

Kendall J.J., Powell E.N., Connor S.J., Bright T.J., Zastrow C.E., 1985, Effects of turbidity on calcification rates, protein concentration and the free amino acid pool of the coral *Acropora cervicornis*. Mar. Biol. 87, 33-46.

Keough M.J., Quinn G.P., 1991, Causality and the choice of measurements for detecting human impacts in marine environments. Aust. J. Mar. Freshwater Res. 42, 539-554.

Khalaf M.A., Kochzius M., 2002, Changes in trophic community structure of shore fishes at an industrial site in the Gulf of Aqaba, Red Sea. Mar. Ecol. Progr. Ser. 239, 287-299.

Khristoforova N.K., Chernova E.N., Selin N.I., 2002, Changes of metal concentrations in soft tissues of Tridacnas with the age of the mollusks. Oceanology 42, 530-535.

Kinsey D.W., 1991, Can we resolve the nutrient issue for the reef ? Search. 22, 117-119.

Kinsey D.W., Davies P.J., 1979, Effects of elevated nitrogen and phosphorus on coral reef growth. Limnol. Oceanogr. 24, 935-939.

Kobayashi N., 1994, Application of eggs of the sea urchin *Diadema setosum* in marine pollution bioassays. Phuket Mar. Biol. Cent. Res. Bull. 59, 51-54.

Koop K., Booth D., Broadbent A., Brodie J., Bucher D., Capone D., Colls J., Dennison W., Erdmann M., Harrison P., Hoegh-Guldberg O., Hutchings P., Jones G.B., Larkum A.W.D., O'Neil J., Steven A., Tentori E., Ward S., Williamson J., Yellowlees D., 2001, ENCORE: The effect of nutrient enrichment on coral reefs. Synthesis of results and conclusions. Mar. Pollut. Bull. 42, 91-120.

Koziol C., Scheffer U., Pancer Z., Krasko A., Müller W.E.G., 1998, Sponges as biomarkers of the aquatic environnement: application of molecular probes. In: Watanabe N.F.Y. (Ed.), Sponge Sciences, Springer-Verlag, Tokyo, pp. 121-132.

Labonne M., Ben Othman D., Luck J.-M., 1998, Recent and past anthropogenic impact on a Mediterranean lagoon: lead isotope constraints from mussel shells. Appl. Geochem. 13, 885-892.

Laboy Nieves E.N., Conde J.E., 2001, Metal levels in eviscerated tissue of shallow water deposit feeding holothurians. Hydrobiologia 459, 19-26.

Lafferty K.D., 1997, Environmental parasitology: What can parasites tell us about human impacts on the environment? Parasitol. Today 13, 251–255.

Langston W.J., Spence S.K., 1995, Biological factors involved in metal concentrations observed in aquatic organisms. In: Tessier, A., Turner, D.R. (Eds.), Metal speciation and bioavailability in aquatic systems. IUPAC Series on Analytical and Physical Chemistry of Environmental Systems 3, 407-478.

Lapointe B.E., 1997, Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnol. Oceanogr. 42, 1119-1131.

Lapointe B.E., Barile P.J., Yentsch C.S., Littler M.M., Littler D.S., Kakuk B., 2004, The relative importance of nutrient enrichment and herbivory on macroalgual communities near Norman's Pond Cay, Exumas cays, Bahamas: A "natural" enrichment experiment. J. Exp. Mar. Biol. Ecol. 298, 275-301.

Larkum A.W.D., Koop K., 1997, ENCORE, algal productivity and possible paradigm shifts. Proc. 8th Int. Coral Reef Symp. 1, 881-884.

Larned S.T., 1998, Nitrogen versus phosphorus limited growth and sources of nutrients for coral reef macroalgae. Mar. Biol. 132, 409-421.

Letourneur Y., Kulbicki M., Labrosse P., 1998, Spatial structure of commercial reef fish communities along a terrestrial runoff gradient in the northern lagoon of New Caledonia. Environ. Biol. Fishes 51, 141-159.

Letourneur Y., Labrosse P., Kulbicki M., 1999, Comparison of commercial fish assemblages of New Caledonian fringing reefs subjected to different levels of ground erosion. Oceanol. Acta 22, 609-622.

Linton D.M., Warner G.F., 2003, Biological indicators in the Caribbean coastal zone and their role in integrated coastal management. Ocean Coast. Manage. 46, 261-276.

Livingston H.G., Thompson G., 1971, Trace element concentrations in some modern corals. Limnol. Oceanogr. 16, 786-796.

Livingston R.J., 2001, Eutrophication process in coastal systems. CRC Press, Boca Raton, pp. 1-10.

Long E., Chapman P., 1985, A sediment quality triad: Measures of sediment contamination, toxicity, an infaunal community composition in Puget Sound. Mar. Pollut. Bull. 16, 405-415.

Loring D.H., Rantala R.T.T., 1992, Manual for the geochemical analysis of marine sediments and suspended particulate matter. Earth Sci. Rev. 32, 235-283.

Lough J.M., Barnes D.J., 1997, Several centuries of variation in skeletal extension, density and calcification in massive *Porites* colonies from the Great Barrier Reef: A proxy for seawater temperature and a background of variability against which to identify unnatural change. J. Exp. Mar. Biol. Ecol. 211, 29-67.

Lowe D.M., Soverchia C., Moore M.N., 1995, Lysosomal membrane responses in the blood and digestive cells of mussels experimentally exposed to fluoranthene. Aquat. Toxicol. 33, 105-112.

MacKenzie K., Williams H.H., Williams B., McVicar A.H., Siddall R., 1995, Parasites as indicators of water quality and the potential use of helminth transmission in marine pollution studies. Adv. Parasitol. 35, 85-144.

Marcogliese D.J., Cone D.K., 1997, Parasite communities as indicators of ecosystem stress. Parasitologia 39, 27-232.

Markert B.A., Breure A.M., Zechmeister H.G., 2003, Bioindicators and Biomonitors: Principles, Concepts, and Applications. Elsevier Science, New York.

Masse J.P., Acquaviva M., Thomassin B., 1989, Bioclastic sedimentary environments in the coral reefs and lagoon of Mayotte Island (Comoro Archipelago, Mozambique Channel, S.W. Indian Ocean). J. Coast. Res. 5, 419-432.

Maven H.K., Sunder rao K., Benko W., Alam K., Huber M.E., Rali T., Burrows I., 1995, Fatty acid and mineral composition of Papua New Guinea Echinoderms. Fish. Technol. 32, 50-52.

Mc Carty L.S., Munkittrick K.R., 1996, Environmental biomarkers in aquatic toxicology: fictions, fantasy, or functional? Human Ecol. Risk Assess. 2, 268-274.

Mc Girr D.J., 1974, Interlaboratory quality control study No. 10: Turbidity and filterable and non filterable residue. Report series No. 37, Inland Waters Directorate, Canada center for Inland Waters, Burlington, Ontario.

Mc Clanahan T.R., Obura D., 1997, Sedimentation effects on shallow coral communities in Kenya. J. Exp. Mar. Biol. Ecol. 209, 103-122.

Mc Comb P.J., 2001, Coastal and sediment dynamics in a high-energy, rocky environment. PhD Thesis, University of Waikato, New Zealand.

Mc Cook L.J., 1999, Macroalgae, nutrients and phase shifts on coral reefs: Scientific issues and management consequences for the Great Barrier Reef. Coral Reefs 18, 1-11.

Mc Cook L.J., Jompa J., Diaz-Pulido G., 2001, Competition between corals and algae on coral reefs: A review of evidence and mechanisms. Coral Reefs 19, 400-417.

Meesters E.H., Hilterman M., Kardinaal E., Keetman M., de Vries M., Bak R.P.M., 2001, Colony-size frequency distributions of scleractinian coral populations: Spatial and interspecific variation. Mar. Ecol. Prog. Ser. 209, 43-54.

Meesters E.H., Nieuwland G., Duineveld G.C.A., Kok A., Bak R.P.M., 2002, RNA/DNA ratios of scleractinian corals suggest acclimatisation/adaptation in relation to light gradients and turbidity regimes. Mar. Ecol. Prog. Ser. 227, 233-239.

Meesters E.H., Bak R.P.M., 1993, Effects of coral bleaching on tissue regeneration potential and colony survival. Mar. Ecol. Prog. Ser. 96, 189-198.

Mendes J.M., Risk M.J., Schwarcz H.P., Woodley J.D., 1997, Stable isotopes of nitrogen as measures of marine pollution: A preliminary assay of coral tissue from Jamaica. Proc. 8th Int. Coral Reef Symp. 2, 1869-1872.

Meyer J.S., 2002, The utility of the terms "bioavailability" and "bioavailable fraction" for metals. Mar. Environ. Res. 53, 417-423.

Miller M.W., Barimo, J., 2002, Assessment of juvenile coral populations at two reef restoration sites in the Florida Keys National Marine Sanctuary: Indicators of success? Bull. Mar. Sci. 69, 395-405.

Miller M.W., Hay M.E., Miller S.L., Malone D., Sotka E.E., Szmant A.M., 1999, Effects on nutrients versus herbivores on reef algae: A new method for manipulating nutrients on coral reefs. Limnol. Oceanogr. 44, 1847-1861.

Monniot F., Martoj R., Monniot C., 1994, Cellular sites of iron and nickel accumulation in ascidians related to the naturally and anthropic enriched New Caledonian environment. Ann. Inst. Océanogr. 70, 205-216.

Moor M.N., 1994, Reactions of Molluscan lysosomes as biomarkers of pollutant-induced cell injury. In: Renzoni, A., Mattei, N., Lorena, L., Fossi, M.C. (Eds.), Contaminants in the environment. A multidiscplinary assessment of risks to man and other organisms. CRC Press, Lewis Publishers, Boca Raton, pp. 111-123.

Moore M.N., 1990, Lysosomal cytochemistry in marine environmental monitoring. Histochemistry 2, 187-191.

Morrison R.J., Narayan S.P., Gangaiya P., 2001, Trace Element Studies in Laucala Bay, Suva, Fiji. Mar. Pollut. Bull. 42, 397-404.

Moss A., Brodie J., Furnas M., 2005, Water quality guidelines for the Great Barrier Reef World Heritage Area: A basis for development and preliminary values. Mar. Pollut. Bull. 51, 76-88.

Mwashote B.M., Jumba I.O., 2002, Quantitative aspects of inorganic nutrient fluxes in the Gazi Bay (Kenya): Implications for coastal ecosystems, Mar. Pollut. Bull. 44, 1194-1205.

Nagelkerken I., Buchan K., Smith G.W., Bonair K., Bush P., Garzon-Ferreira J., Botero L., Gayle P., Harvell C.D., 1997, Widerspread disease in Caribbean sea fans: 2. Patterns of infection and tissue loss. Mar. Ecol. Prog. Ser. 160, 255-263.

Naim O., 1993, Seasonal responses of a fringing reef community to eutrophication (Reunion Island, Western Indian Ocean). Mar. Ecol. Prog. Ser. 99, 137-151.

Nascimento I.A., Smith D.H., Pereira S.A., Sampaio de Araujo M.M., Silva M.A., Mariani A.M., 2000, Integration of varying responses of different organisms to water and sediment quality at sites impacted and not impacted by the petroleum industry. Aquat. Ecosyst. Health Manage. 3, 449-458.

Negri A.P., Heyward A.J., 2001, Inhibition of coral fertilisation and larval metamorphosis by tributyltin and copper. Mar. Environ. Res. 51, 17-27.

Nicholson S., 1999, Cytological and Physiological biomarker responses from green mussels, *Perna viridis* (L.) transplanted to contaminated sites in Hong Kong coastal waters. Mar. Pollut. Bull. 39, 261-268.

Nugues M.M., 2002, Impact of a coral disease outbreak on coral communities in St. Lucia: What and how much has been lost? Mar. Ecol. Prog. Ser. 229, 61-71.

O'Connor T.P., Cantillo A.Y., Lauenstein G.G., 1994, Monitoring of temporal trends in chemical contamination by the NOAA National Status and Trends Mussel Watch Project. In: Kramer K.J.M. (Ed.), Biomonitoring of coastal waters and estuaries. CRC Press. Boca Raton FL, pp. 29-45 + App.

Olsgard F., Somerfield P.J., Carr M.R., 1998, Relationships between taxonomic resolution, macrobenthic community along patterns and disturbance. Mar. Ecol. Progr. Ser. 172, 25-36

Omori K., Hirano T., Takeoka H., 1994, The Limitations to Organic Loading on a Bottom of a Coastal Ecosystem. Mar. Pollut. Bull. 28, 73-80.

Orpin A.R., Ridd P.V., Thomas S., Anthony K.R.N., Marshall P., Oliver J., 2004, Natural turbiditiy variability and weather forecasts in risk management of anthropogenic sediment discharge near sensitive environments. Mar. Pollut. Bull. 49, 602-612.

Ouillon S., Douillet P., Andrefouet S., 2004, Coupling satellite data with *in situ* measurements and numerical modeling to study fine suspended-sediment transport: A study for the lagoon of New Caledonia. Coral Reefs 23, 109-122.

Overstreet R.M., 1997, Parasitological data as monitors of environmental health. Parasitologia 39, 169-175.

Pages J., Andréfouët S., Délesalle B., Prasil V., 2001, Hydrology and trophic state in Takapoto Atoll lagoon: Comparison with other Tuamotu lagoons. Aquat. Living Resour. 14, 183-193

Patel B., Balani M. C., Patel S., 1985, Sponge "sentinel" of heavy metals. Sci.Tot. Environ. 41, 143-152.

Perez T., 2000, Evaluation de la qualité des milieux côtiers par les spongiaires : État de l'art. Bull. Soc. Zool. Fr. 125, 17-25.

Perez T., 2001, Qualité de l'environnement marin littoral : Étude des spongiaires pour la bioévaluation des peuplements de substrats durs. Thèse de Doctorat, Université de la Méditerranée, Marseille.

Perez T., Garrabou J., Sartoretto S., Harmelin J.G., Francour P., Vacelet, J., 2000, Mass mortality of marine invertebrates: An unprecedented event in the NW Mediterranean. C.R. Acad. Sci. Paris 323, 853-865.

Peters E.C., Gassman N.J., Firman J.C., Richmond R.H., Power E.A., 1997, Ecotoxicology of marine tropical ecosystems. Environ. Toxicol. Chem. 16, 12-40.

Pocklington P., Wells P.G., 1992, Polychaetes, key taxa for marine environmental quality monitoring. Mar. Pollut. Bull. 24, 593-598.

Price G.D., Pearce N.J.G., 1997, Biomonitoring of Pollution by Cerastoderma edule from the British Isles: A laser ablation ICP-MS study. Mar. Pollut. Bull. 34, 1025-1031.

Raimbault P., Slawyk G., Coste B., Fry J., 1990, Feasibility of measuring an automated colorimetric procedure for the determination of seawater nitrate in the 0 to 100 nM range: Examples from field and culture. Mar. Biol. 104, 347-351.

Rainbow P.S., 1995, Biomonitoring of heavy metal availability in the marine environment. Mar. Pollut. Bull. 31, 183-192.

Ramos A.A., Inoue Y., Ohde S., 2004, Metal contents in Porites corals: Anthropogenic input of river run-off into a coral reef from an urbanized area, Okinawa. Mar. Pollut. Bull. 48, 281-294.

Ramirez M., Gonzalez H., Ablanedo N., Torres I., 1990, Heavy metals in macroalgae of Havana's Northern littoral, Cuba. Chem. Ecol. 4, 49-55.

Rasheed M., Wild C., Franke U., Huettel M., 2004, Benthic photosynthesis and oxygen consumption in permeable carbonate sediments at Heron Island, Great Barrier Reef, Australia. Estuar. Coast. Shelf Sci. 59, 139-150.

Rauret G., López-Sánchez J.F., Sahuquillo A., Rubio R., Davidson C., Ure A., Quevauviller P., 1999, Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials. J. Environ. Monitor. 1, 57-61.

Rayment G.E., Barry G.A., 2000, Indicator tissues for heavy metal monitoring – Additional attributes. Mar. Pollut. Bull. 41, 353-358.

Reichelt A.J., Jones G.B., 1994, Trace metals as tracers of dredging activity in Cleveland Bay – Field and laboratory studies. Aust. J. Freshwater Res. 45, 1237-1257.

Reichelt-Brushett A.J., Harrison P.L., 2000, The effect of copper on the settlement success of larvae from the Scleractinian coral *Acropora tenuis*. Mar. Pollut. Bull. 41, 385-391.

Ridd P.V., Larcombe P., 1994, Biofouling control for optical backscatter suspended sediment sensors. Mar. Geol. 116, 255-258.

Riegel B., Branch G.M., 1995, Effects of sediment on the energy budgets of four scleractinian (Bourne, 1900) and five alcyonacean (Lamouroux 1816) corals. J. Exp. Mar. Biol. Ecol. 186, 259-275.

Riegel B., Heine C., Branch G.M., 1996, Function of funnel-shaped coral growth in a high-sedimentation environment. Mar. Ecol. Prog. Ser. 145, 87-93.

Ringwood A.H., 1991, Short-term accumulation of cadmium by embryos, larvae, and adults of an Hawaiian bivalve, *Isognomon californicum.* J. Exp. Mar. Biol. Ecol. 149, 55-66.

Ringwood A.H., 1992, Comparative sensitivity of gametes and early developmental stages of a seaurchin species (*Echinometra mathaei*) and a bivalve species (*Isognomon californicum*) during metal exposures. Arch. Environ. Contam. Toxicol. 22, 288-295.

Ringwood A.H., 1993, Age-specific differences in cadmium sensitivity and bioaccumulation in bivalve molluscs. Mar. Environ. Res. 35, 35-39.

Risk M.J., Dunn J.J., Allison W.P., Horrill C., 1994, Reef monitoring in Maldives and Zanzibar: low-tech and high-tech science. In: Ginsburg R.N. (Ed.), Proc. Colloquium Global aspects of coral reefs: Health, hazards and history. Rosenstiel School of Marine and Atmospheric Science, University of Miami, pp. 66-72.

Rojas M.T., Acuna J.A., Rodriguez O.M., 1998, Metales traza en el pepino de mar Holothuria (Halodeima) mexicana del Caraibe de Costa Rica. Rev. Brasil. Biol. 46, 215-220.

Roméo M., Sidoumou Z., Gnassia-Barelli M., 2000, Heavy metals in various Molluscs from the Mauritanian coast. Bull. Environ. Contam. Toxicol. 65, 269-276.

Rossi S., Snyder M.J., 2001, Competition for space among sessile marine invertebrates: changes in HSP70 expression in two Pacific cnidarians. Biol. Bull. 201, 385-393.

Rumbold D.G., Snedeker S.C., 1997, Evaluation of bioassays to monitor surface microlayer toxicity in tropical marine waters. Arch. Environ.l Contam. Toxicol. 32, 135140.

Rumbold D.G., Snedeker S.C., 1999, Sea-surface microlayer toxicity off the Florida Keys. Mar. Environ. Res. 47, 457-472.

Runnalls L.A., Coleman M.L., 2003, Record of natural and anthropogenic changes in reef environments (Barbados, West Indies) using laser ablation ICP-MS and sclerochronology on coral cores. Coral Reefs 22, 416-426.

Russ G., 1984, Distribution and abundance of herbivorous grazing fishes in the central Great Barrier Reef. I. Levels of variability across the entire continental shelf. Mar. Ecol. Progr. Ser. 20, 23-34.

Sanders B., 1988, The role of the stress proteins response in physiological adaptation of marine molluscs. Mar. Environ. Res. 24, 207-210.

Sanders B., 1993, Stress proteins in aquatic organisms: An environmental perspective. Crit. Rev. Toxicol. 23, 49-75.

Schaffelke B., 2001, Surface alkaline phosphatase activities of macroalgae on coral reefs of the central Great Barrier Reef, Australia. Coral Reefs 19, 310-317.

Schaffelke B., Klump D.W., 1998, Short-term nutrient pulses enhance growth and photosynthesis of the coral reef macroalga Sargassum baccularia. Mar. Ecol. Progr. Ser. 170, 95-105.

Schönberg C.H.L., Wilkinson, C.R., 2001, Induced colonization of corals by a clionid bioeroding sponge. Coral Reefs 20, 69-76.

Schrimm M., Heussner S., Buscail R., 2002, Seasonal variations of downward particle fluxes in front of a reef pass (Moorea Island, French Polynesia). Oceanol. Acta 25, 61-70

Serfor-Armah Y., Nyarko B.J.B., Osae E.K., Carboo D., Anim-Sampong S., Seku F., 2001, Rhodophyta seaweed species as bioindicators for monitoring element pollutants in the marine ecosystem of Ghana. Water Air Soil Pollut. 127, 243-253.

Sinderman C.J., 1983, Parasites as natural tags for marine fish: A review. NAFO Sci. Counc. Stud. 6, 63-71.

Smith G.W., Ives L.D., Nagelkerken I.A., Ritchie K.B., 1996, Caribbean sea-fan mortalities. Nature 383, 487.

Smith J.E., Smith C.M., Hunter C.L., 2001, An experimental analysis of the effects of herbivory and nutrient enrichment on benthic on benthic community dynamics on Hawaiian reef. Coral Reefs 19, 332-342.

Smith S.V., 1984, Phosphorus versus Nitrogen limitation in the marine environment. Limnol. Oceanogr. 29, 1149-1160.

Sorokin Y.I., 1993, Coral reef ecology. Springer, Berlin.

Soule D.F., 1988, Marine organisms as indicators: Reality or wishful thinking? In: Soule D.F., Kleppel G.S. (Eds.), Marine organisms as indicators. Springer-Verlag, New York, pp. 1-12.

Stafford-Smith M.G., 1993, Sediment-rejection efficiency of 22 species of Australian scleractinian corals. Mar. Biol. 115, 229-243.

Steedman R.J., 1991, Occurrence and environmental correlates of black spot disease in stream fishes near Toronto, Ontario. Trans. Am. Fish. Soc. 120, 494-499.

Steemann-Nielsen E., Measurement of the production of the organic matter in the sea by mean of carbon 14. Nature 167, 684-685.

Steinert S.A., Pickwell G.V., 1993, Induction of HSP70 proteins in mussels by ingestion of tributyltin. Responses of Marine Organisms to Pollutants, Part 35, 89-93.

Steven A.D.L., Broadbent A.D., 1997, Growth and metabolic responses of *Acropora palifera* to long term nutrient enrichment. Proc.8th Int. Coral Reef Symp. 1, 867-872.

Stimson J., Larned S.T., Conklin E., 2001, Effects of herbivory, nutrient levels, and introduced algae on the distribution and abundance of the invasive macroalga *Dictyosphaeria cavernosa* in Kanohe Bay, Hawaii. Coral Reefs 19, 343-357.

Strickland J.D.H., Parsons T.R., 1972, A practical handbook of sea water analysis. Bull. Fish. Res. Board Can. 167, 1-311.

Szefer P., Frelek K., Szefer K., Lee C.-B., Kim B.-S., Warzocha J., Zdrojewska I., Ciesielski T., 2002, Distribution and relationships of trace metals in soft tissue, byssus and shells of *Mytilus edulis trossulus* from the southern Baltic. Environ. Pollut. 120, 423-444.

Szmant A.M., 2001, Introduction to the special issue of Coral reefs on "Coral reef algal community dynamics. Why are coral reefs world-wide becoming overgrown by algae? Coral Reefs 19, 299-302.

Szmant A.M., 2002, Nutrient enrichment on coral reefs: Is it a major cause of coral reef decline? Estuaries 25, 743-766.

Tack F.M.G., Verloo M.G., 1995, Chemical speciation and fractionation in soil and sediment heavy metal analysis: A review. Int. J. Environ. Analyt. Chem. 59, 225-238.

Tack F.M.G., Verloo M.G., 1999, Single extractions versus sequential extraction for the estimation of heavy metal fractions in reduced and oxidised dredged sediments. Chem. Speciation Bioavailability 11, 43-50.

Thacker R.W., Ginsburg D.W., Paul V.J., 2001, Effects of herbivore exclusion and nutrient enrichment on coral reef macroalgae and cyanobacteria. Coral Reefs 19, 318-329.

Thomas S., Ridd P.V., Day G., 2003, Turbidity regimes over fringing coral reefs near a mining site at Lihir Island, Papua New Guinea. Mar. Pollut. Bull. 46, 1006-1014.

Tom M., Douek J., Yankelevich I., Bosch T.C.G., Rinkevich B., 1999, Molecular characterization of the first Heat Shock Protein 70 from a reef coral. Biochem. Biophys. Res. Communic. 262, 103-108.

Viarengo A., Canesi L., Pertica M., Mancinelli G., Accomando R., Smaal A.C., Orunesu M., 1995, Stress on stress response: A simple monitoring tool in the assessment of a general stress syndrome in mussels. Mar. Environ. Res. 39, 245-248.

Viollier E., Rabouille C., Apitz S.E., Breuer E., Chaillou G., Dedieu K., Furukawa Y., Grenz C., Hall P., Janssen F., Morford J.L., Poggiale J.-C., Roberts S., Shimmield T., Taillefert M., Tenberg A., Wenzhöfer F., Witte U., 2003, Benthic biogeochemistry: state of the art technologies and guidelines for the future of in situ survey, J. Mar. Biol. Ecol. 285-286, 5-31.

Ward S., Harrison P., 2000, Changes in gametogenesis and fecundity of acroporid corals that were exposed to elevated nitrogen and phosphorus during the ENCORE experiment. J. Exp. Mar. Biol. Ecol. 246, 179-221.

Warwick R.M., 1993, Environmental impact studies on marine communities - pragmatical considerations. Aust. J. Ecol. 18, 63-80.

Warwick R.M., Clarke K. R., 1993, Comparing the severity of a disturbance: A meta-analysis of marine macrobenthic data. Mar. Ecol. Progr. Ser. 92, 221-231.

Warwick R.M., Clarke K.R., 1995, New “biodiversity" measures reveal a decrease in taxonomic distinctness with increasing stress. Mar. Ecol. Progr. Ser. 129, 301-305.

Webb J.A., Keough M.J., 2002, Measurement of environmental trace-metal levels with transplanted mussels and diffusive gradients in thin films (DGT): a comparison of techniques. Mar. Pollut. Bull. 44, 222-229.

Weber D.F., Weber M.K., 1998, The water quality of Kingston Harbour: Evaluating the use of the planktonic community and traditional water quality indices. Chem. Ecol. 14, 357-374.

Weisberg S.B., Dauer D., Schaffner L., Diaz R., Frithsen J. 1997, An estuarine benthic index of biotic integrity (B-IBI) for Cheasapeake bay. Estuaries 20, 149-156.

White W.H., Harborne A.R., Sotheran I.S., Walton R., Foster-Smith R.L., 2003, Using an acoustic ground discrimination system to map coral reef benthic classes. Int. J. Remote Sensing 24, 2641-2660.

Widdows J., Donkin P., Brinsley M.D., Evans S.V., Salkeld P.N., Franklin A., Law R.J., Waldock M.J., 1995, Scope for growth and contaminant levels in North Sea mussels Mytilus edulis. Mar. Ecol. Progr. Ser. 127, 131-148.

Wiens M., Ammar M.S., Nawar A.H., Koziol C., Hassanein H.M.A., Eisinger M., Muller M., Muller W.E.G., 2000, Induction of heat-shock (stress) protein gene expression by selected natural and anthropogenic disturbances in the octocoral *Dendronephthya klunzingeri*. J. Exp. Mar. Biol. Ecol. 245, 265-276.

Wilkinson C.R., Cheshire A.C., 1990, Comparisons of sponge populations across the barrier reefs of Australia and Belize: Evidence for higher productivity in the Caribbean. Mar. Ecol. Prog. Ser. 67, 285-294.

Williams D.M., Hatcher A.I., 1983, Structure of fish communities on outer slopes of inshore, mid-shelf and outer shelf reefs of the Great Barrier Reef. Mar. Ecol. Progr. Ser. 10, 239-250.

Wilson J.G., Jeffrey D.W., 1994, Benthic biological pollution indices in estuaries. CRC Press Inc. 17, 311-327.

Wittenberg M., Hunte W., 1992, Effects of eutrophication and sedimentation on juvenile corals. I. Abundance, mortality and community structure. Mar. Biol. 112, 131-138.

Woolfe K., Larcombe P., 1999, Terrigeneous sedimentation and coral reef growth: A conceptual framework. Mar. Geol. 155, 3331-345.

Yates K.K., Halley R.B., 2003, Measuring coral reef community metabolism using new benthic chamber technology. Coral Reefs 22, 247-255.

Zea S., 1994, Patterns of coral and sponge abundance in stressed coral reefs at Santa Marta, Colombian Caribbean. In: Van Soest, R.W.M., van Kempen, T.M.G., Braekman, J.C. (Eds.), Sponges in time and space; Biology, Chemistry, Paleontology. A.A. Balkema. Rotterdam, pp. 257-264.

Zhang H., Davison W., 2000, Direct *in situ* measurements of labile inorganic and organically bound metal species in synthetic solutions and natural waters using diffusive gradients in thin films. Analyt. Chem. 72, 4447-4457.

Zhang H., Davison W., Mortimer R.J.G., Krom M.D., Hayes P.J., Davies I.M., 2002, Localised remobilization of metals in a marine sediment. Sci. Total Environ. 296, 175-187.