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Coral health on reefs near mining sites in New Caledonia

T. Heintz[1,*], J. Haapkylä[2], A. Gilbert[1]

[1]Sopronér, 1 bis rue Berthelot, BP 3583, 98846 Nouméa Cedex, New Caledonia
[2]College of Marine and Environmental Sciences and ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, QLD 4811, Australia

ABSTRACT: Coral health data are poorly documented in New Caledonia, particularly from reefs chronically subject to anthropogenic and natural runoff. We investigated patterns of coral disease and non-disease conditions on reefs situated downstream of mining sites off the coast of New Caledonia. Surveys were conducted in March 2013 at 2 locations along the west coast and 2 locations along the east coast of the main island. Only 2 coral diseases were detected: growth anomalies and white syndrome. The most prevalent signs of compromised health at each location were sediment damage and algal overgrowth. These results support earlier findings that sedimentation and turbidity are major threats to inshore reefs in New Caledonia. The Poritidae-dominated west coast locations were more subject to sediment damage, algal overgrowth and growth anomalies compared to the Acroporidae-dominated east coast locations. If growth form and resistance of coral hosts influence these results, differences in environmental conditions including hydrodynamism between locations may also contribute to these outputs. Our results highlight the importance of combining coral health surveys with measurements of coral cover when assessing the health status of a reef, as reefs with high coral cover may have a high prevalence of corals demonstrating signs of compromised health.

KEY WORDS: Coral disease · Sediment damage · Algal overgrowth · Mining · New Caledonia

INTRODUCTION

Coral reefs around the world have been in serious decline during the last decades, due to many factors including over-harvesting (Jackson et al. 2001), climate change (Hughes et al. 2003), terrestrial runoff (De'ath & Fabricius 2010) and coral diseases (Harvell et al. 2007). Diseases have caused high levels of coral mortality and have induced changes on reefs in the Caribbean (Aronson & Precht 2001, Sutherland et al. 2004, Cróquer & Weil 2009), the Great Barrier Reef (GBR) of Australia (Willis et al. 2004, Page & Willis 2008, Sato et al. 2009) and other Indo-Pacific locations (Haapkylä et al. 2007, Aeby et al. 2011, Ross et al. 2012, Couch et al. 2014). Coral health is also influenced by environmental parameters including turbidity and sedimentation (Rogers 1990, Erftemeijer et al. 2012) and biological processes such as predation by crown-of-thorns starfish (Pratchett 2010) or corallivore gastropods (Rotjan & Lewis 2008) and competition with other organisms such as algae (Gowan et al. 2014).

New Caledonia is surrounded by the second-longest barrier reef and has the largest lagoon in the world presenting a large array of different types of reefs (Andréfouët & Torres-Pulliza 2004, Andréfouët et al. 2009) with high biodiversity (Payri & Richer de Forges 2006). Currently, more species (8500) have been documented from New Caledonian reefs than from any other reef area in the world (Payri & Richer de Forges 2006). New Caledonian reefs have been preserved from major large-scale disturbances includ-

*Corresponding author: tom.heintz@gmail.com

ing bleaching events or crown-of-thorns starfish outbreaks compared to other Indo-Pacific regions (Wantiez 2008, Adjeroud et al. 2009, Sweatman et al. 2011), but the island is regularly subject to cyclones and depressions (Guillemot et al. 2010).

New Caledonia is exposed to a specific anthropogenic threat linked to an active nickel mining industry that promotes extensive runoff particularly during the wet season (Fernandez et al. 2006). New Caledonia is the world's third biggest producer of nickel, and as a consequence, open-cast mining sites are present all along the main island and contribute to soil erosion that constitutes a major chronic threat to the marine ecosystem (Fernandez et al. 2006, Morrison et al. 2013). Apart from mining activity, the low population density in the country (14 inhabitants km^{-2} in 2014; www.isee.nc), limits anthropogenic impacts on the marine ecosystem away from urban areas.

Previous coral health surveys around New Caledonia detected a low abundance of coral diseases, mainly growth anomalies and white syndrome (Tribollet et al. 2011, Work et al. 2014). Overall, those authors found a higher prevalence of coral disease at inshore reefs compared to offshore reefs, and this first survey highlighted a uniformly low prevalence of coral lesions on New Caledonian reefs. However, coral health data are missing from reefs chronically subject to anthropogenic and natural runoff, especially from reefs along the east coast of New Caledonia. Recording coral health data on reefs that are subject to runoff from land is important, as runoff has negative influences on inshore reefs (Fabricius et al. 2013), and sedimentation and turbidity have been linked to coral disease (Haapkylä et al. 2011, Pollock et al. 2014).

Sedimentation may transmit coral pathogens from marine or terrestrial substrates onto nearby corals (Hodgson 1990), reduce the amount and quality of ambient light available for photosynthesis by the corals' endosymbiotic algae (*Symbiodinium*) and inhibit the heterotrophic feeding efficiency of corals, reducing the energy intake of both symbiotic and asymbiotic corals (Falkowski et al. 1990, Richmond 1993). Corals may shed sediment through mucus production and ciliary movement, but this burdens the corals' reduced energy budgets (Peters & Pilson 1985, Riegl & Branch 1995).

The aim of the present study was to examine patterns of coral disease and non-diseased conditions on fringing reefs around the main island of New Caledonia where mining activity is present. This is the first survey of coral disease and other indicators of compromised health on reefs situated downstream of nickel mining sites in New Caledonia.

MATERIALS AND METHODS

Study locations

Four inshore locations were surveyed in March 2013 (wet season) around New Caledonia in the South Pacific (Fig. 1). Kaala (20° 36.9' S, 164° 18.9' E) and Nepoui (21° 20.6' S, 164° 59.7' E) on the west coast, and Thio (21° 37.0' S, 166° 15.3' E) and Borendi (21° 47.2' S, 166° 27.9' E) on the east coast. Kaala, Nepoui and Thio are under the influence of nickel mining sites currently in activity, whereas Borendi is situated downstream of an old mining site where mining activity ceased in the 1950s. Thio and Borendi are under oceanic influence due to large passes separating small barrier reefs, whereas the barrier reef is continuous with small passes at Kaala and Nepoui (Andréfouët & Torres-Pulliza 2004). Moreover, Nepoui's sites are situated within a large bay which favours high water residence time.

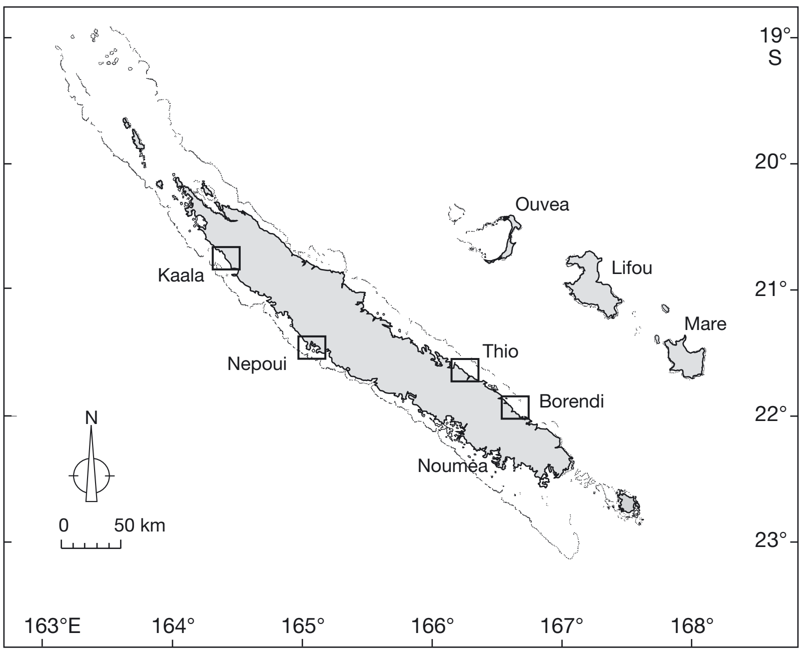

Fig. 1. New Caledonia, showing the 4 study locations (squares)

Disease identification

Coral diseases and signs of compromised health were recorded following macroscopic descriptions provided by Beeden et al. (2008). Seven categories were used in the data analysis: white syndrome (WS), growth anomalies (GAs), bleaching (including total and partial bleaching, bleached spots, bleached patches and stripes), pigmentation responses (including pigmentation response and trematodiasis), predation (including *Drupella*, *Coralliophila*, crown-of-thorns starfish lesions and fish bites), algal overgrowth (including coral tissue overgrown by macroalgae or calcareous algae) and sediment damage (including tissue loss associated with accumulation of fine sediment, combined with algal filaments and/or surface mucus). Abnormally pigmented lesions on corals were classified as 'pigmentation responses'. Pigmentation responses were not considered as a disease but as a generalized defence response to localized stress (Palmer et al. 2008).

Survey method

A total of 4 locations, 12 sites and 36 transects were sampled. Four sites were surveyed at Borendi, 3 each at Kaala and Thio, and 2 at Nepoui. At each site, three 20 × 1 m (1 m on the slope side of the transect) belt transects were laid on the reef crest (1–3 m deep), following the depth contour of the reef. The first transect was located randomly, and the 2 additional transects were located 15 m from the previous transect, continuously along the reef crest. Each transect was treated as 1 replicate in the analyses. Each coral colony (>5 cm in diameter) within each transect was counted and identified to family level and categorized as healthy, diseased or demonstrating signs of compromised health. Each colony that was located partially in a transect was included in the colony count.

Disease prevalence was calculated within each transect by dividing the number of diseased colonies by the total number of coral colonies. Family-specific prevalence was calculated as the number of cases of a specific disease or lesion divided by the number of appropriate hosts encountered. If a family was not present on a transect, this taxon did not have any prevalence taken into account in the mean per site and location.

Coral cover was estimated at the family level along the same transects using the line intercept method (English et al. 1997).

Sediment granulometry

Sediment grain size distribution was assessed using samples from each location during our disease survey. One site at Thio could not be sampled. A light-weight Van Veen grab sampler (capacity 1.8 l) was used to sample the upper sediment layer between the reef slope and the bottom at each site, along the first transect. Samples were placed in single-use vinyl bags (Whirl-pack) and frozen for storage. After being oven-dried (60°C, 3 d), samples were weighed and sieved on a vibrating granulometric column using the following mesh sizes in diameter units: <50 µm, 50 µm–2 mm, >2 mm. The 3 fractions obtained were expressed as weight percentage of the initial bulk sample. The mean proportions of the 3 classes of grain size were calculated per location. In this study, we used sediment grain size distribution as a proxy of hydrodynamic conditions, as it reflects retention and removal of sediments (Fabricius 2005)

Statistical analyses

Multivariate approaches were used to examine differences in coral community structure and in disease assemblages between sites and locations using PRIMER version 6.1.10 with the permutational analysis of variance (PERMANOVA) extension (Anderson et al. 2008).

A non-metric multidimensional scaling plot, based on a Bray-Curtis similarity matrix made from square-root transformed data at the transect level, was used to illustrate similarities of coral communities between locations. We used a 2-factor nested analysis of similarity (ANOSIM) to test differences in coral assemblages between sites nested within locations, and a SIMPER analysis was run on the data matrix. SIMPER decomposes Bray-Curtis dissimilarities between all pairs of samples to identify the families that contributed most to differences between locations (Clarke & Warwick 2001). Seven most abundant coral families were considered as separate taxonomic groups, and the other families were grouped into a category named 'Other'. Differences in total scleractinian coral cover between locations were tested using a 2-way nested ANOVA with Statistica 9 (StatSoft).

Different coral health conditions at each site — based on normalised prevalences of bleaching, pigmented responses, GAs, predation, sediment damage, algal overgrowth and WS per transect — were analysed using a principal component analysis (PCA) to visualise differences between locations and between sites. A PERMANOVA was used to test for differences in diseases assemblages between sites and locations.

Differences in the fraction of each of the 3 sediment grain size classes between locations were tested using a non-parametric Kruskal-Wallis test.

Table 1. Mean ± SE prevalence (%) of coral diseases, signs of compromised health and coral cover (% ± SE) at each study location in New Caledonia (see Fig. 1)

Lesion/disease	Borendi	Kaala	Nepoui	Thio
Bleaching	2.17 ± 0.50	1.94 ± 0.58	1.14 ± 0.56	0.87 ± 0.35
Pigmentation	3.22 ± 0.80	11.1 ± 2.70	0.31 ± 0.31	2.07 ± 0.47
Growth anomaly	1.52 ± 0.44	3.01 ± 1.03	4.16 ± 2.54	1.78 ± 0.60
Predation	3.10 ± 0.57	3.30 ± 1.43	4.91 ± 1.83	1.78 ± 0.47
Sedimentation	7.19 ± 1.53	28.7 ± 3.37	34.1 ± 3.90	19.1 ± 2.40
Algal overgrowth	4.14 ± 0.97	30.2 ± 5.19	14.6 ± 5.23	2.32 ± 0.89
White syndrome	1.07 ± 0.47	0	0	0.07 ± 0.07
Coral cover	28.8 ± 4.27	49.0 ± 3.53	19.7 ± 2.21	68.0 ± 4.95

RESULTS

Coral cover and community structure

Mean cover of scleractinian corals was significantly different between locations (ANOVA: $F = 37.5$, $p < 0.001$) and sites (ANOVA: $F = 3.1$, $p < 0.05$). It was highest at Thio (mean ± SE: 68.0 ± 5.0%) and Kaala (48.9 ± 3.5%) compared to Borendi (28.8 ± 4.3%) and Nepoui (19.7 ± 2.2%; Table 1).

Significant differences in average coral community composition were detected between locations (ANOSIM: Global R = 0.948, $p < 0.001$) and between sites (ANOSIM: Global R = 0.495, $p < 0.001$). Kaala and Nepoui were dominated by the Poritidae family, and Kaala was also characterized by Agariciidae (Fig. 2A). SIMPER analysis confirmed this trend, with Poritidae driving similarities for Kaala and Nepoui (67.6% and 63.8% contributions to similarity for these locations, respectively). On the east coast, Thio and Borendi were dominated by Acroporidae, and Borendi was also characterized by a high cover of soft corals (25.4 ± 4.9%). Alcyoniidae and Acroporidae drove similarities for Borendi (SIMPER: 65.3% contribution to similarity for both families), and Acroporidae alone led similarities for Thio (SIMPER: 60.7% contribution to similarity). A high variability in coral community composition was generally observed among sites within locations (Fig. 2A).

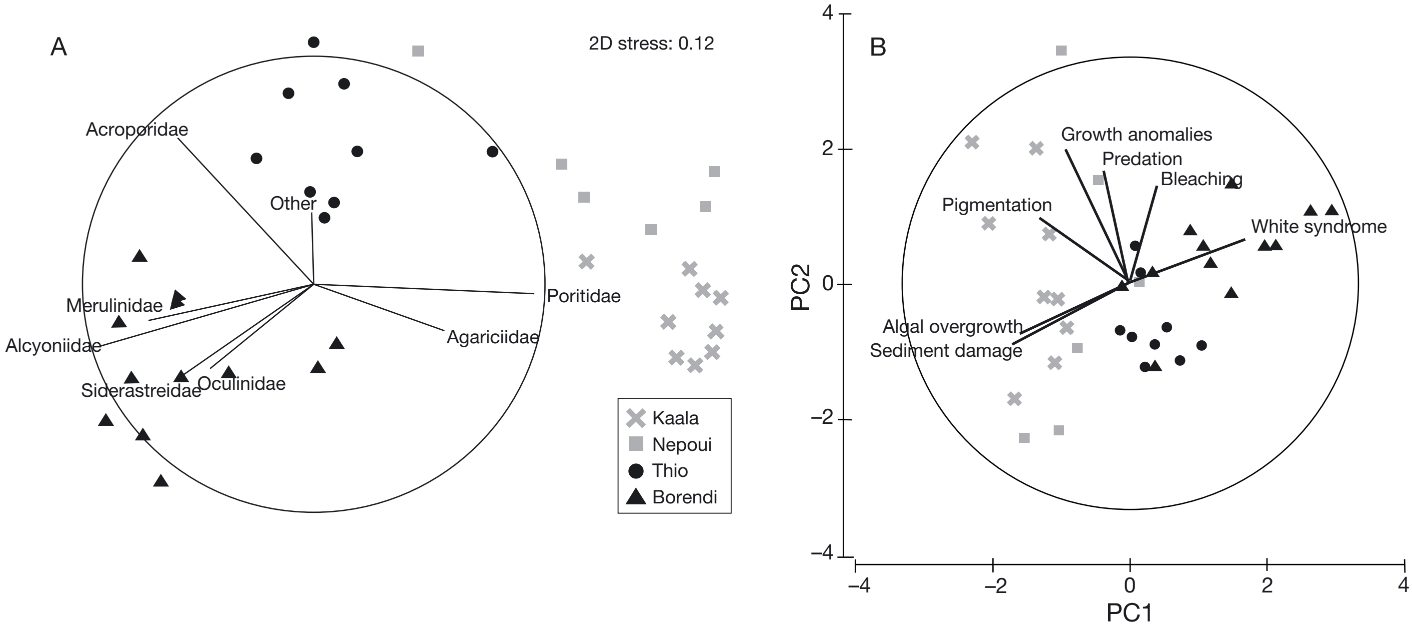

Fig. 2. (A) Non-metric multidimensional scaling plot with vectors (Pearson's correlation) representing similarities (Bray-Curtis matrix) of coral assemblages between study locations based on coral cover per family across replicate transects. Data were square-root transformed prior to analysis. (B) Principal component analysis of coral disease assemblages at the 4 study locations based on average prevalence across replicate transects. PC1 and PC2 axes together capture 59.1% of the total variation in disease assemblages

Coral health

The results indicated that coral health was significantly different between locations (PERMANOVA; $F = 5.80$, $p < 0.001$) and between sites (PERMANOVA; $F = 2.21$, $p < 0.001$). A distinction between the west coast (Nepoui and Kaala) and the east coast (Thio and Borendi) was observed (Fig. 2B, Table 1). Algal overgrowth was highest at Kaala (mean ± SE: 30.2 ± 5.19%) and Nepoui (14.6 ± 5.23%), whereas sediment damage was highest at Nepoui (34.1 ± 3.90%) and similar in Kaala (28.7 ± 3.37%; Fig. 2B, Table 1). Although much lower at Thio and Borendi, algal overgrowth and sediment damage remained the more prevalent signs of compromised health at each location (Table 1). The only diseases observed in the present study were WS and GAs. WS was only observed at Thio (0.1 ± 0.07%) and Borendi (1.1 ± 0.47%). The mean prevalence of GAs ranged from 1.5 ± 0.44% at Borendi to 4.2 ± 2.54% at Nepoui. The prevalence of predation ranged from 1.8 ± 0.47% at Thio to 4.9 ± 1.83% at Nepoui. Bleaching did not exceed 2.5% of prevalence at each location, and the prevalence of pigmentation responses was more than 3 times higher at Kaala (11.1 ± 2.70%) compared to the other locations.

Disease prevalence per taxon

The susceptibility of different coral families to diseases varied between locations (Fig. 3). Acroporidae was the most diseased taxon in our study. At Borendi, 3.6% of Acroporidae demonstrated signs of WS,

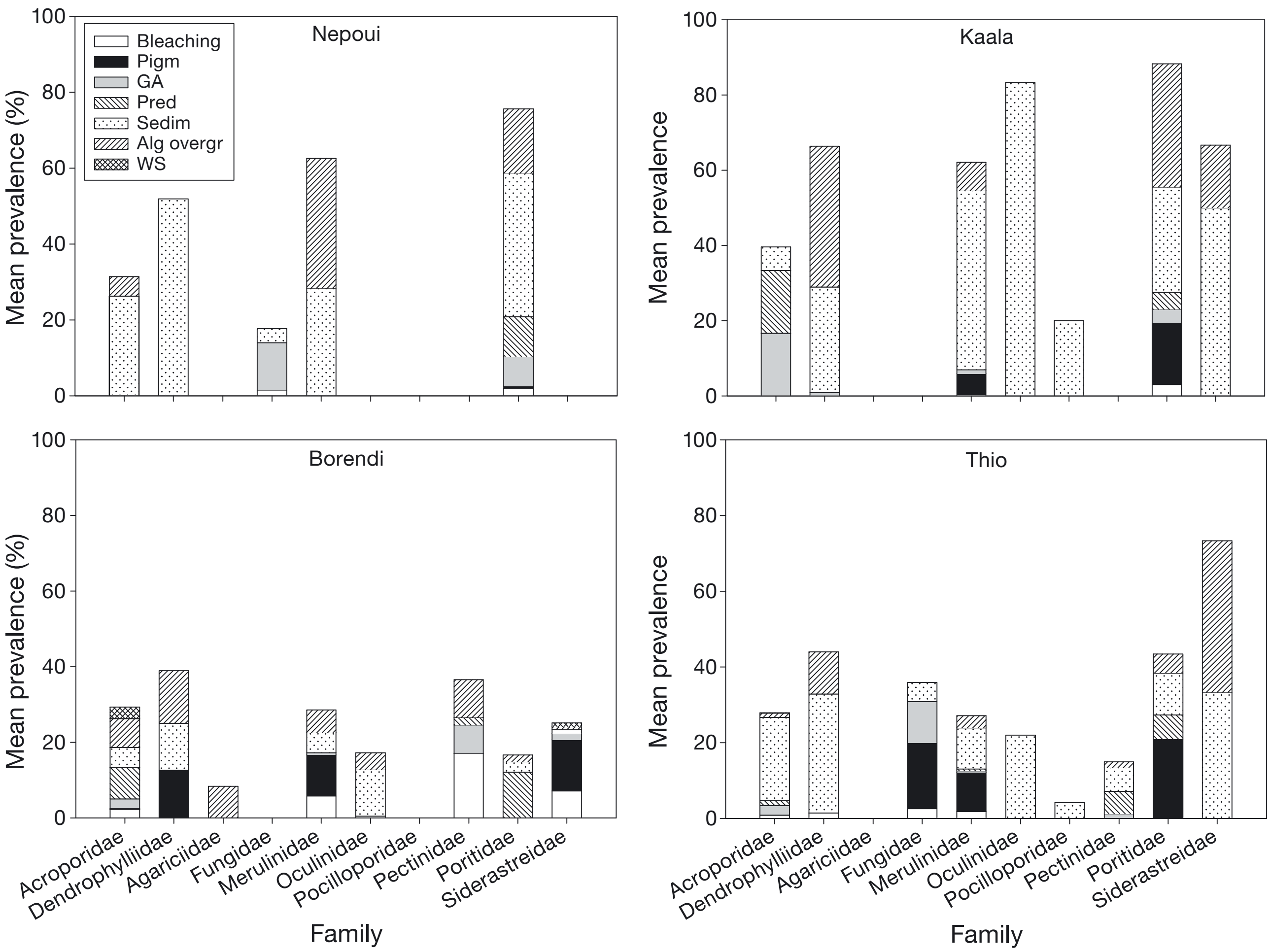

Fig. 3. Mean prevalence (%) of coral disease and compromised health per coral taxon at each study location (Pigm: pigmentation; GA: growth anomaly; Pred: predation; Sedim: sedimentation; Alg overgr: algal overgrowth, WS: white syndrome). Prevalence was calculated as the number of cases of a specific disease or sign of compromised health divided by the number of appropriate hosts encountered on each transect

whereas 16.7% of Acroporidae colonies had GAs at Kaala. Overall, the west coast had a higher prevalence of signs of compromised health, algal overgrowth and sediment damage, than the east coast. At Kaala, Oculinidae had the highest number of corals with sediment damage (83.3%), whereas 40% of the Siderastreidae colonies at Thio had algal overgrowth. The highest number of colonies with pigmentation responses (20.9%) was found on Poritidae at Thio (Fig. 3).

Sediment granulometry

One class of grain size showed significant differences in its fraction between locations: diameter <50 µm ($p < 0.05$). However, the p-value of the Kruskal-Wallis test for the 2 other classes is comprised between 0.05 and 0.06, indicating a location effect that was almost significant. Sediments at Kaala and Nepoui, both situated on the west coast, are mainly composed of mud (diameter <50 µm), which represented 77.6 ± 12.1% (mean ± SE) and 84.0 ± 15.3%, respectively (Fig. 4). On the other hand, sediments at Borendi and Thio, both situated on the east coast, were mainly composed of fine and coarse sand (50 µm < diameter < 2 mm), representing 82.3 ± 5.1% and 67.0 ± 22.9%, respectively (Fig. 4). Mud (diameter <50 µm) was also well represented in the samples of Thio, with a fraction of about 25%.

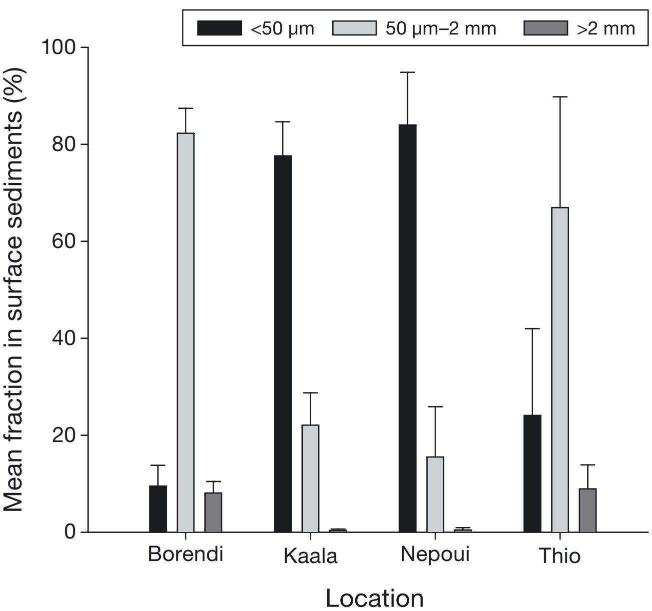

Fig. 4. Mean ± SE fraction (%) of 3 grain size classes in the surface sediments at each study location in New Caledonia

DISCUSSION

This is the first coral health study on reefs situated downstream of mining sites in New Caledonia. Our results indicate that the investigated locations were characterized by a medium to high coral cover. The only 2 coral diseases found were WS and GAs. WS was detected only on the east coast at Thio and Borendi, with low prevalences similar to the WS prevalence values detected in Indonesia (Haapkylä et al. 2009) and on the GBR (Haapkylä et al. 2010). However, WS should be monitored closely, as it has the potential to cause widespread and rapid loss of coral cover (Bourne et al. 2015). The prevalence of GAs was up to 4 times higher than the prevalence of WS in our study.

Our results support the preliminary coral disease inventories in New Caledonia conducted by Tribollet et al. (2011) and Work et al. (2014). The low abundance of common Indo-Pacific coral diseases suggests that New Caledonian reefs are healthier than Caribbean reefs (Sutherland et al. 2004), the GBR (Sato et al. 2009, Haapkylä et al. 2013, Pollock et al. 2014) and other Indo-Pacific locations (Haapkylä et al. 2009, Page et al. 2009, Sandin et al. 2008). The result may also reflect the fact that New Caledonian reefs have thus far been understudied with regard to coral disease.

Sediment damage and algal overgrowth, signs of compromised health, affected all of our study locations and support earlier findings that sedimentation and turbidity are major threats to inshore reefs in New Caledonia (Morrison et al. 2013). In New Caledonia, sedimentation is due to both natural and anthropogenic inputs (Fernandez et al. 2006, Fichez et al. 2010), the latter being linked to the mining industry. To date, the southwestern lagoon of New Caledonia has been the main study area for modelling of geochemical processes (Fernandez et al. 2006), circulation and suspended sediment transport (Ouillon et al. 2010) as well as coastal erosion (Dumas et al. 2010), but no studies are available from other areas off the mainland. No studies on the influences of mining, comparing reference sites to affected sites by measuring sedimentation rates, have been conducted along the coast.

Geomorphological differences may explain the differences in coral and lesion assemblages between the east (Acroporidae dominated) and west (Poritidae dominated) coasts, as sedimentation and water circulation processes are likely to differ between the coasts (Andréfouët & Torres-Pulliza 2004). The barrier reef is continuous along the west coast and dis-continuous along the east coast, allowing a connection with clear oceanic waters (Andréfouët et al. 2009). This pattern may induce stronger hydrodynamic movement along the east coast, supported by the south-easterly trade winds that influence surface currents (Jouon et al. 2006) and reduce particle deposition as shown in our results on sediment grain sizes at Thio and Borendi. Along the west coast, sediment grain size samples from Kaala and Nepoui reflect high water residence times, as they are mainly composed of mud. Indeed, hydro-dynamism is among the factors controlling sedimentation rates (Fabricius 2005), and this pattern may partially explain the differences observed on sediment damage prevalences between the 2 coasts. The highest prevalence of sediment damage at Nepoui, situated in a large semi-enclosed bay with the highest proportion of mud in the sediments, strengthens these findings. Mining activities are likely to enhance natural soil erosion and increase inputs of fine sediments into the Caledonian lagoon (Bird et al. 1984). However, many other factors, including depth or coral community composition with different susceptibilities to lesions, may also have contributed to the differences observed in the prevalence of sediment damage between our study locations.

Despite a high prevalence of algal overgrowth and sediment damage, we recorded a medium to high coral cover at each location, with the lowest coral cover recorded being 19.7%. High coral cover has been previously observed in different bays in the southern part of the island, and this pattern is characteristic of some Western Pacific reefs (Adjeroud et al. 2010). New Caledonia's fringing reefs have been under erosion pressure for more than a century (Ouillon et al. 2010), and it is likely that coral communities have developed mechanisms of adaptation and tolerance to high turbidity and sedimentation levels (Larcombe et al. 1995).

Massive *Porites* are stress tolerant and particularly resistant to harsh conditions including turbid environments (Darling et al. 2012). Our results show a high prevalence of lesions in this genus, especially on the west coast, and confirm that, despite their high resistance, *Porites* colonies can be partially affected by tissue loss or lesions due to sediment deposition. At Nepoui and Kaala, where the prevalence of sediment damage was the highest, sediment rates may exceed the sub-lethal threshold that *Porites* colonies can handle to remain entirely healthy (Flores et al. 2012).

Tribollet et al. (2011) found a 30% prevalence of discolouration, including pink spots resembling *Porites* trematodiasis. Our field records do not allow the identification of trematodiasis (Benzoni et al. 2010); we have therefore classified it as a pigmentation response, a defence response to localized stress (Palmer et al. 2008). The highest *Porites* spp. cover and the highest prevalence of pigmentation responses were found at Kaala, where sediment composition reflects high water residence times. Pigmentation responses have been linked to high sedimentation on the GBR (Pollock et al. 2014). The results of the present study with regard to a possible link between sedimentation and pigmentation responses were not as clear, as the prevalence of pigmentation responses was highest at Kaala, a site with a high proportion of mud in the sediment, but second highest at Borendi, where the prevalence of sediment damage was the lowest and the sediment composition reflects low deposition rates.

In conclusion, this study highlights the low disease prevalence and the high prevalence of sediment damage and algal overgrowth, signs of compromised health, on reefs situated in close proximity to mining sites in New Caledonia. Further studies linking water quality, hydrodynamics and sedimentation to ecological and biological processes are needed to better understand the effect of mining on New Caledonian reefs. This study also highlights the importance of incorporating coral health surveys to monitor the influence of the mining industry on reefs, as coral cover alone may not reflect the compromised health status of coral colonies.

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LITERATURE CITED

Adjeroud M, Michonneau F, Edmunds P, Chancerelle Y and others (2009) Recurrent disturbances, recovery trajectories, and resilience of coral assemblages on a South Central Pacific reef. Coral Reefs 28:775–780

Adjeroud M, Fernandez JM, Carroll AG, Harrison PL, Penin L (2010) Spatial patterns and recruitment processes of coral assemblages among contrasting environmental conditions in the southwestern lagoon of New Caledonia. Mar Pollut Bull 61:375–386

Aeby GS, Williams GJ, Franklin EC, Haapkylä J and others (2011) Growth anomalies on the coral genera *Acropora* and *Porites* are strongly associated with host density and human population size across the Indo-Pacific. PLoS ONE 6:e16887

Anderson MJ, Gorley RN, Clarke KR (2008) PERMANOVA+ for PRIMER: guide to software and statistical methods. PRIMER-E, Plymouth

Andréfouët S, Torres-Pulliza D (2004) Atlas des recifs coralliens de Nouvelle-Caledonie. IFRECOR Nouvelle-Calédonie, IRD, Nouméa

Andréfouët S, Cabioch G, Flamand B, Pelletier B (2009) A reappraisal of the diversity of geomorphological and genetic processes of New Caledonian coral reefs: a synthesis from optical remote sensing, coring and acoustic multibeam observations. Coral Reefs 28:691–707

Aronson RB, Precht WF (2001) White-band disease and the changing face of Caribbean coral reefs. Hydrobiologia 460:25–38

Beeden R, Willis BL, Raymundo LJ, Page CA, Weil E (2008) Underwater cards for assessing coral health on Indo-Pacific Reefs. Coral Reef Targeted Research and Capacity Building for Management Program. Currie Communications, Melbourne

Benzoni F, Galli P, Pichon M (2010) Pink spots on *Porites*: not always a coral disease. Coral Reefs 29:153

Bird ECF, Dubois JP, Iltis JA (1984) The impacts of opencast mining on the rivers and coasts of New Caledonia. NRTS-25/UNUP-505. United Nations University Press, Tokyo

Bourne DG, Ainsworth TD, Pollock FJ, Willis BL (2015) Towards a better understanding of white syndromes and their causes on Indo-Pacific coral reefs. Coral Reefs 34: 233–242

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. PRIMER-E, Plymouth

Couch CS, Garriques JD, Barnett C, Preskitt L, Cotton S, Giddens J, Walsh W (2014) Spatial and temporal patterns of coral health and disease along leeward Hawaii Island. Coral Reefs 33:693–704

Cróquer A, Weil E (2009) Spatial variability in distribution and prevalence of Caribbean scleractinian coral and octocoral diseases. II. Genera-level analysis. Dis Aquat Org 83:209–222

Darling ES, Alvarez-Filip L, Oliver TA, McClanahan TR, Côté IM (2012) Evaluating life-history strategies of reef corals from species traits. Ecol Lett 15:1378–1386

De'ath G, Fabricius K (2010) Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecol Appl 20:840–850

Dumas P, Printemps J, Mangeas M, Luneau G (2010) Developing erosion models for integrated coastal zone management: a case study of The New Caledonia west coast. Mar Pollut Bull 61:519–529

English S, Wilkinson C, Baker V (1997) Survey manual for tropical marine resources, 2nd edn. Australian Institute of Marine Science, Townsville

Erftemeijer PLA, Riegl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: a review. Mar Pollut Bull 64: 1737–1765

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar Pollut Bull 50:125–146

Fabricius KE, De'ath G, Humphrey C, Zagorskis I, Schaffelke B (2013) Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. Estuar Coast Shelf Sci 116: 57–65

Falkowski PG, Jokiel PL, Kinzie RA (1990) Irradiance and corals. In: Dubinsky Z (ed) Ecosystems of the world: coral reefs. Elsevier, Amsterdam, p 89–107

Fernandez JM, Ouillon S, Chevillon C, Douillet P, Fichez R, Gendre RL (2006) A combined modelling and geochemical study of the fate of terrigenous inputs from mixed natural and mining sources in a coral reef lagoon (New Caledonia). Mar Pollut Bull 52:320–331

Fichez R, Chifflet S, Douillet P, Gérard P and others (2010) Biogeochemical typology and temporal variability of lagoon waters in a coral reef ecosystem subject to terrigeneous and anthropogenic inputs (New Caledonia). Mar Pollut Bull 61:309–322

Flores F, Hoogenboom MO, Smith LD, Cooper TF, Abrego D, Negri AP (2012) Chronic exposure of corals to fine sediments: lethal and sub-lethal impacts. PLoS ONE 7: e37795

Guillemot N, Chabanet P, Le Pape O (2010) Cyclone effects on coral reef habitats in New Caledonia (South Pacific). Coral Reefs 29:445–453

Gowan JC, Tootell JS, Carpenter RC (2014) The effects of water flow and sedimentation on interactions between massive *Porites* and algal turf. Coral Reefs 33:651–663

Haapkylä J, Seymour AS, Trebilco J, Smith D (2007) Coral disease prevalence and coral health in the Wakatobi Marine Park, south-east Sulawesi, Indonesia. J Mar Biol Assoc UK 87:403–414

Haapkylä J, Unsworth RKF, Seymour AS, Melbourne-Thomas J, Flavell M, Willis BL, Smith DJ (2009) Spatio-temporal coral disease dynamics in the Wakatobi Marine National Park, South-East Sulawesi, Indonesia. Dis Aquat Org 87:105–115

Haapkylä J, Melbourne-Thomas J, Flavell M, Willis B (2010) Spatiotemporal patterns of coral disease prevalence on Heron Island, Great Barrier Reef, Australia. Coral Reefs 29:1035–1045

Haapkylä J, Unsworth RKF, Flavell M, Bourne DG, Schaffelke B, Willis BL (2011) Seasonal rainfall and runoff promote coral disease on an inshore reef. PLoS ONE 6: e16893

Haapkylä J, Melbourne-Thomas J, Flavell M, Willis BL (2013) Disease outbreaks, bleaching and a cyclone drive changes in coral assemblages on an inshore reef of the Great Barrier Reef. Coral Reefs 32:815–824

Harvell D, Jordàn-Dahlgren E, Merkel S, Rosenberg E and others (2007) Coral disease, environmental drivers, and the balance between coral and microbial associates. Oceanography 20:172–195

Hodgson G (1990) Tetracycline reduces sedimentation damage to corals. Mar Biol 104:493–496

Hughes TP, Baird AH, Bellwood DR, Card M and others (2003) Climate change, human impacts, and the resilience of coral reefs. Science 301:929–933

Jackson JBC, Kirby MX, Berger WH, Bjorndal KA and others (2001) Historical overfishing and the recent collapse of coastal ecosystems. Science 293:629–637

Jouon A, Douillet P, Ouillon S, Fraunié P (2006) Calculations of hydrodynamic time parameters in a semi-opened coastal zone using a 3D hydrodynamic model. Cont Shelf Res 26:1395–1415

Larcombe P, Ridd PV, Prytz A, Wilson B (1995) Factors controlling suspended sediment on inner-shelf coral reefs, Townsville, Australia. Coral Reefs 14:163–171

Morrison RJ, Denton GRW, Bale Tamata U, Grignon J (2013) Anthropogenic biogeochemical impacts on coral reefs in the Pacific Islands: an overview. Deep-Sea Res II 96:5–12

Ouillon S, Douillet P, Lefebvre JP, Le Gendre R and others (2010) Circulation and suspended sediment transport in a coral reef lagoon: the south-west lagoon of New Caledonia. Mar Pollut Bull 61:269–296

Page CA, Willis BL (2008) Epidemiology of skeletal eroding band on the Great Barrier Reef and the role of injury in the initiation of this widespread coral disease. Coral Reefs 27:257–272

Page CA, Baker DM, Harvell CD, Golbuu Y and others (2009) Influence of marine reserves on coral disease prevalence. Dis Aquat Org 87:135–150

Palmer CV, Mydlarz LD, Willis BL (2008) Evidence of an inflammatory-like response in non-normally pigmented tissues of two scleractinian corals. Proc R Soc Lond B Biol Sci 275:2687–2693

Payri C, Richer de Forges B (2006) Une vue d'ensemble de la biodiversité marine de Nouvelle-Calédonie [Compendium of New Caledonian marine species: overview]. In: Compendium of marine species from New Caledonia. Document Scientifiques et Techniques. Rep No 1297–9635. IRD, Nouméa, p 10–13

Peters EC, Pilson MEQ (1985) A comparative study of the effects of sedimentation on symbiotic and asymbiotic colonies of the coral *Astrangia danae* Milne Edwards and Haime 1849. J Exp Mar Biol Ecol 92:215–230

Pollock FJ, Lamb JB, Field SN, Heron SF and others (2014) Sediment and turbidity associated with offshore dredging increase coral disease prevalence on nearby reefs. PLoS ONE 9:e102498

Pratchett MS (2010) Changes in coral assemblages during an outbreak of *Acanthaster planci* at Lizard Island, northern Great Barrier Reef (1995–1999). Coral Reefs 29: 717–725

Richmond RH (1993) Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. Am Zool 33:524–536

Riegl B, Branch GM (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

Rogers CS (1990) Responses of coral reefs and reef organisms to sedimentation. Mar Ecol Prog Ser 62:185–202

Ross M, Stender Y, White D, Aeby G (2012) Outbreak of the coral disease, Montipora White Syndrome in Maui, Hawaii. Proc 12th Int Coral Reef Symp, Cairns, art. no. 16B-3

Rotjan RD, Lewis SM (2008) Impact of coral predators on tropical reefs. Mar Ecol Prog Ser 367:73–91

Sandin SA, Smith JE, DeMartini EE, Dinsdale EA and others (2008) Baselines and degradation of coral reefs in the northern Line Islands. PLoS ONE 3:e1548

Sato Y, Bourne DG, Willis BL (2009) Dynamics of seasonal outbreaks of black band disease in an assemblage of *Montipora* species at Pelorus Island (Great Barrier Reef, Australia). Proc R Soc Lond B Biol Sci 276:2795–2803

Sutherland KP, Porter JW, Torres C (2004) Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. Mar Ecol Prog Ser 266:273–302

Sweatman HPA, Delean S, Syms C (2011) Assessing loss of coral cover on Australia's Great Barrier Reef over two decades with implications for longer-term trends. Coral Reefs 30:521–531

Tribollet A, Aeby G, Work T (2011) Survey and determination of coral and coralline algae diseases/lesions in the lagoon of New Caledonia. CRISP, Nouméa

Wantiez L (2008) Les récifs coralliens de Nouvelle-Calédonie en 2006: états des lieux et réseau de suivi. Rev Ecol Terre Vie 63:117–132

Willis BL, Page CA, Dinsdale AD (2004) Coral disease on the Great Barrier Reef. In: Rosenberg E, Loya Y (eds) Coral health and disease. Springer-Verlag, Berlin, p 69–104

Work TM, Aeby GS, Lasne G, Tribollet A (2014) Gross and microscopic pathology of hard and soft corals in New Caledonia. J Invertebr Pathol 120:50–58

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