Coral and algal community primary succession on new vertical substrate at Rackham's Cay, Port Royal, Jamaica

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Abstract: Jamaica's trans-shipment industry is amongst the largest in the Caribbean with 90% of trans-shipment activities occurring in Kingston Harbour. The eastern ship channel is populated with patch and fringing coral reefs. In 2002, approximately 20% of an originally sloping face of Rackham's Cay, on the southern edge of the channel, was cut vertically to 18m and dredged to widen the channel. The successional changes on the newly created vertical limestone wall was assessed between 2009 and 2012 at 5m, 10m and 15m depths using bi-annual photographs of fixed 1 m^2 quadrats. Photographs were analyzed using Coral Point Count. No colonization of either algal or coralline species was observed at 15m. Initially calcareous and fleshy algae dominated at 5m but showed a gradual decrease over time. Calcareous algae dominated at 10m and increaseed gradually over the 4 years. Stony corals at both 5m and 10m had overall low cover and slow colonization; the shallower depth had more coverage (4.1% maximum in 2011). *Siderastrea sidera* -which dominated Rackham's Cay before dredging- was consistently present in low coverage. Colonization by species of *Acropora* and *Scolymia* indicate slower but better succession at 10m. Ten years following dredging activities, colonization and recruitment have been slow but successful at 5m and 10m; species previously described as abundant lead the colonization. We recommend limiting coral relocation activities to depths not exceeding 10m. Rev. Biol. Trop. 62 (Suppl. 3): 107-114. Epub 2014 September 01.

Key words: Rackham's Cay, new vertical substrate, coral colonization, succession.

Jamaica's trans-shipment industry is amongst the largest in the Caribbean with 90% of trans-shipment activities occurring in the Kingston Harbour (latitude 17º58'N and longitude 76º48'W). This has been a lucrative industry for the Jamaican government, with current plans to diversify and expand this sector to keep abreast with a global marketplace and for continued significant contribution to Jamaica's economy. The Port Authority of Jamaica (PAJ), which owns and operates Kingston Container Terminals (KCT), earned JMD$12.57 billion in 2009. The operations at KCT generated JMD$8.50 billion which was 67% of total income for Port Authority. In 2001, the Port Authority of Jamaica commenced infrastructure expansion to increase the capacity at the Kingston Container Terminal (KCT). This infrastructure upgrade was done in an effort to maximize the potential earnings generated by the KCT, which would increase the benefit to Jamaica. The improvement is required to increase access for Post Panamax container vessels to Kingston Harbour and the KCT.

Kingston Harbour's main ship channel which runs on the east side of the Port Royal Cays is approximately 16.5m deep and is populated with the patch and fringing coral reefs known to be found throughout the area. The Port Royal Cays area has seven small cays, including Rackham's Cay which is positioned on the south-west edge of the ship channel. To facilitate the improved access to Kingston Harbour, the PAJ proposed the removal of the northern portion of the coral reef at Rackham's Cay, which was partially obstructing the south-western portion of the ship channel. This 'capital' dredging exercise, carried out in 2002, was also deemed justified based on a record of repeated groundings occurring in the area on e.g. Gun Cay and Beacon Shoal as vessels maneuver during entry to or egress from the Harbour (Gayle, Wilson-Kelly & Green, 2005).

The dredging exercise involved the removal of approximately 20% of Rackham's Cay and deepening of the east channel depth to 18 m at the area of the opening between Rackham and Gun Cays. The result was a vertical wall of new substrate on the east side of Rackham's Cay. As part of the dredging activity, corals were transplanted to help mitigate the loss of coral species, however, the newly created substrate was not subject to any post-dredging transplanting or seeding activities (e.g. Jaap, 2000; Jaap, Hudson, Dodge & Gillian, 2006). The Port Authority of Jamaica was mandated by Jamaica's National Environment and Planning Agency (NEPA) to monitor the transplanted corals for a period of five years however, there was no stipulation for the monitoring of the new vertical substrate to elucidate changes over time on the new substrate.

In 2009 the Centre for Marine Sciences (CMS) of the University of the West Indies (UWI) received a grant from the Environmental Foundation of Jamaica (EFJ) to monitor the newly created vertical substrate at Rackham's Cay for five years. The objective of the study was to investigate the development of pioneer coral and algal communities and follow the initial stages of succession created by the cutting of the hard substrate as an indication of biological recovery.

The aims of this study were therefore:

1. To indicate the establishment of coral and algae species on the new vertical substrate at Rackham's Cay.
2. To assess pioneer coral and algal community development using taxonomic composition and % cover.
3. To identify the water depth for optimal coral recruitment in the area of the ship channel near Rackham's Cay.

MATERIALS AND METHODS

The successional changes on the new vertical substrate (wall) were assessed between 2009 and 2012. Bi-annual photographs of fixed 1 m^2 quadrats at 5m, 10m and 15m depths were taken during the period. A total of three 1 m^2 permanent quadrats were randomly established at each depth along the vertical substrate of the providing a total of nine permanent quadrats. Photographs were taken with the camera positioned 1 m above the substrate and analyzed using Coral Point Count with Excel extensions (CPCe) version 3.5 software (Kohler & Gill, 2006). Genera and species, where possible, were identified from the images of the quadrats with the use of Human & DeLoach (2003) with checks of Coralpedia (http//coralpedia.bio.warwick.ac.uk) as a cross-reference. Tracing each organism identified (using the area measurement feature of CPCe) and calibration of the image, allowed the programme to compute the area occupied by the organism in question as a percentage of the total quadrat area (percentage cover). The percentage cover of major organisms/substrate categories measured over time at each depth was checked for normality and transformed where necessary (Sokal & Rohlf, 1981) before one-way analysis of variance (ANOVA, $p = 0.05$), tests were applied, using Statistica V.7, to indicate whether significant variability existed between depths and years. Diversity was calculated by the CPCe programme using the Shannon-Weaver Index (Kohler and Gill, 2006).

RESULTS

Analysis of the photographs revealed that only quadrats located at 5m and 10m depths had live species present throughout the study period. Examination of quadrats at 15m indicated silt covered carbonate material as no colonization by algae, sponge or coralline species was observed at the 15m depth.

Species identification: Five species of corals were identified throughout the course of this study: *Undaria agaricites, Acropora palmata, Montastrea faveolata, Siderastrea siderea* and *Scolymia cubensis* however they were observed at different depths and established at different times. *U. agaricites* and *M. faveolata* were identified from the pictorial data capture but were not captured in the random data capture based on the CPCe method employed. The algae observed were only identified to genus level. Those identified were *Halimeda* spp. *Caulerpa* spp., *Dictyota* sp., *Sargassum* sp., *Udotea* sp. and an unidentified encrusting algae. *Halimeda* spp. had the greatest percentage cover (13.75 % cover at 5m and 31.1 % 10m depths) and comprised the dominant genera of calcareous algae. The vertical wall of the Rackham Cay was colonized primarily by algae with other taxonomic groups being added over time.

Species and community changes: While the assessment of the photographic records at Rackham's Cay suggested subtle changes in the community over time and depths, diversity was the only parameter that varied significantly over the years (ANOVA, p = 0.037), with only hard corals (ANOVA p = 0.004) and calcareous algae (ANOVA, p = 0.039) varying significantly with depth. This was supported by a notable change in the percentage cover of species which were consistently present over time and a change in the species composition as new species occupied the area over-time.

The algae *Caulerpa* spp., *Halimeda* spp. and *Dictyota* sp. were present at the 5m depth on each sample occasion. However, the abundance as indicated by % cover was variable, increasing from the first sample occasion to a maximum at the second or third sample occasion and declining thereafter (Figure 1). Other common species such as sponge and the coral *Siderastrea siderea* did not demonstrate maximum % cover until the fourth and fifth sample occasion. Species such as *Agaricia agaricites*, *Sargassum* spp., a species of gorgonian and the coral *Acropora palmata* all demonstrated successional changes as they were present on some sample occasions for one, two or three occasions then later would disappear at subsequent sample occasions (Table 1). It was also observed that *A. palmata* replaced the gorgonian species which had earlier replaced *Agaricia agaricities,* suggesting a successional process.

TABLE 1
Percentage cover values for each taxon found at 5m over the sampling period (dates) arranged in reverse sequence of establishment

SPECIES		Jun-09	Nov-09	Jul-10	Nov-11	Dec-12
Acropora palmata	Y2					0.1
Gorgonian	Y1				8.8	
Sargassum sp.	Y2		0.5	0.9	1.2	
Agaricia agaricites	Y2	0.1	0.1	0.1		
Udotea sp.	Y2			0.2		
Encrusting algae	Y2	1.2			0.1	1.7
Halimeda sp.	Y1	7.1	23.1	17.6	7.5	12.9
Caulerpa sp.	Y1	1.3	11.6	1.2	1.1	2.0
Dictyota sp.	Y1	3.9	3.2	13.3	7.7	0.9
Sponge	Y1	4.1	3.6	4.8	4.1	6.9
Siderastrea siderea	Y1	1.3	1.4	3.7	4.1	1.8

* Y1 or Y2 after each taxon name indicates the y-axis scale with which the values for that taxon are associated.

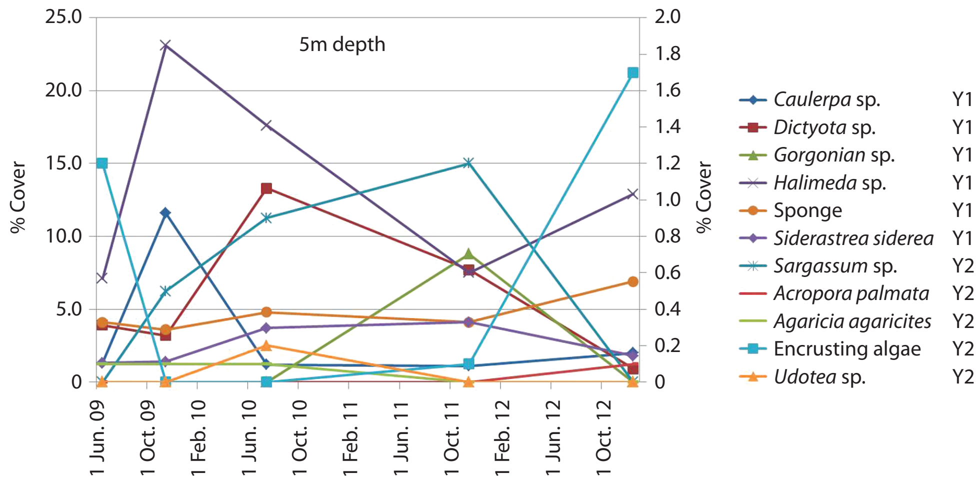

Fig. 1. Percentage cover values for each taxon found at 5m over the sampling period (dates on the x-axis). Y1 or Y2 after each taxon name in the legend indicates the y-axis scale with which the plot for that taxon is associated.

The species pattern was similar at the 10m depth, but with different species being involved in the successional changes. *Caulerpa* spp., *Dictyota* sp., *Halimeda* spp., the sponge and *Siderastrea siderea* were always present with % cover maxima on sampling occasion 4 for *Dictyota* sp. and *Halimeda* spp. and occasion 2 for *S. siderea* and the sponge (Figure 2). In these deeper waters *Udotea* sp. and an encrusting alga, which were present at the start of the sampling programme, disappeared by occasion 3 and 4 respectively and *Scolymia cubensis* and a gorgonian were added to the species composition in the quadrats, providing further successional evidence. These added species remained throughout all other sample occasions and the community at 10m was further enriched with *Agaricia agaricities* being present on the 4th occasion and *A. palmata* on the 5th sampling occasion as species change over time continued (Table 2).

Community change over time, as demonstrated by the significant (ANOVA, p = 0.037) change in diversity, also indicated that

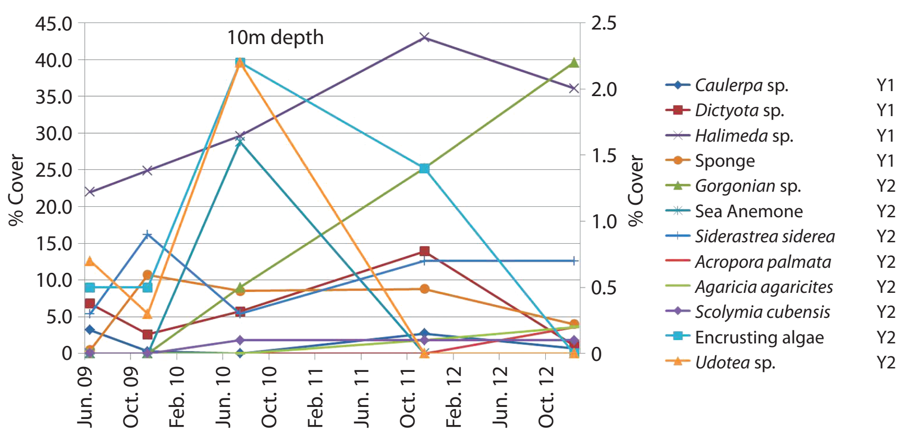

Fig. 2. Percentage cover values for each taxon found at 10m over the sampling period (dates on the x-axis). Y1 or Y2 after each taxon name in the legend indicates the y-axis scale with which the plot for that taxon is associated.

communities at 5m were more diverse that those at 10m for each sampling occasion (Figure 3). Moreover the difference in diversity became larger with the passage of time, with 10m depth samples losing greater diversity than 5m depth samples. While the absolute values are somewhat low (0.63 to 0.81 at 5m and 0.35 to 0.61 at 10m) the pattern of increase then decrease in diversity with the process of succession is clear (Figure 3).

DISCUSSION

The study focused on the medium to long term changes occurring on the newly created bare vertical substrate referred to as the "cut face" of the cay. There are not many examples of colonization of new hard substrate by corals in the Caribbean. Most studies describe primary colonization in relation to artificial substrates (Vermeij, 2006) or newly created

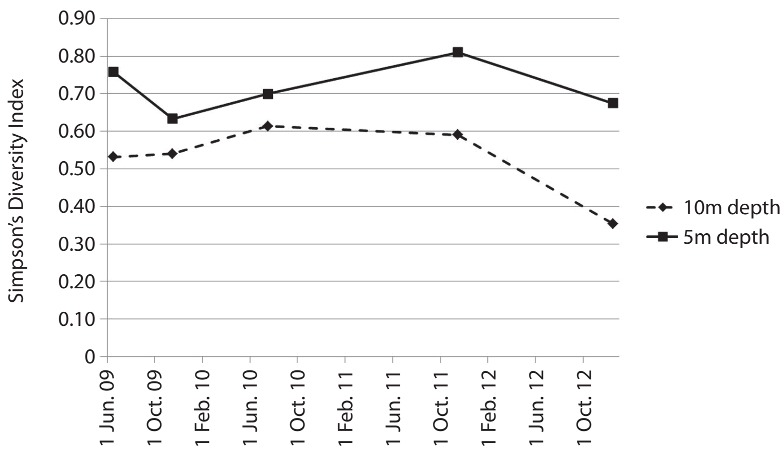

Fig. 3. Simpsons index of diversity for communities at 5m and 10m depths at Rackham's Cay calculated at each of five sample occasions.

TABLE 2
Percentage cover values for each taxon found at 10m over the sampling period (dates) arranged in reverse sequence of establishment. Y1 or Y2 after each taxon name indicates the y-axis scale with which the values for that taxon are associated

SPECIES		Jun-09	Nov-09	Jul-10	Nov-11	Dec-12
Acropora palmata	Y2					0.2
Agaricia agaricites					0.1	0.2
Sea Anemone	Y2			1.6		
Gorgonian	Y2			0.5	1.4	2.2
Scolymia cubensis	Y2			0.1	0.1	0.1
Encrusting algae	Y2	0.5	0.5	2.2	1.4	
Udotea sp.	Y2	0.7	0.3	2.2		
Caulerpa sp.	Y1	3.2	0.3		2.7	0.7
Dictyota sp.	Y1	6.8	2.6	5.7	13.9	1.1
Halimeda sp.	Y1	22.0	24.9	29.6	43.0	36.1
Sponge	Y1	0.5	10.7	8.5	8.8	4.0
Siderastrea siderea	Y2	0.3	0.9	0.3	0.7	0.7

* Y1 or Y2 after each taxon name indicates the y-axis scale with which the values for that taxon are associated.

volcanic rock in areas outside the Caribbean (e.g. Grigg & Maracos, 1974, Tomascik, Van Woesik & Mah, 1996) and so this study presents a unique opportunity, albeit in the Port Royal Cays area where percentage cover of corals (Mendes, 1992) and community diversity (McNaught, 2007) has been reported to be low. Percentage cover of coral at Rachkam's cay "cut face" was one fifth the average from a coral reef at Dairy Bull near Discovery Bay sampled in the same years, which had 15 % cover (NEPA, 2012). However, algal cover which was nine times higher than coral cover was also lower that island averages of 35.5% (NEPA, 2012).

With the absence of a pre-dredging survey, it is impossible to determine the exact nature of the benthic community at the specific depths assessed in this investigation. However, studies in the general area of the Port Royal cays gave insight to the dominant members of the community (Mendes, 1992; Miller, 1996). Throughout this study, the dominance of calcareous and fleshy algae was as reported previously (McNaught, 2007; NEPA, 2012), with the concomitant overall low cover and slow colonization of hard corals and shallower depth having greater coral coverage. Previous reports also indicated that S*iderastrea siderea* dominated Rackham Cay before dredging (Mendes, 1992; McNaught, 2007; Center for Marine Sciences, 2005) and therefore would be expected to colonize fastest and be the dominant coral species. Current data supports this suggestion, with S*iderastrea siderea* being present in all quadrats and on all sample occasions but with very low percentage cover. With no colonization observed at 15m it is clear that the threshold for recovery in the area of Rackham's Cay is between 10 and 15m. This threshold requires further investigation to identify the causative factors.

The primary community succession (Walker & Delmoral, 2003), on the vertical wall at Rackham's Cay, was evident at both the 5 and 10m depths and mirrored the classical description of disappearance of initial species having modified the substrate, to be replaced by more competitively advanced species and a shift to seral communities (Houston & Smith, 1987). In the early stages of this succession, widely accepted pioneer algal genera (*Halimeda*, *Dictyota* and *Caulerpa*) as well as the coral S*iderastrea siderea* dominated with sponges, while the later introduction of gorgonians and the once Jamaican dominant coral *Acropora palmata,* suggest the seral stage has begun. The community in deeper waters (10m) demonstrated additional successional rigour with the coral *Scolymia cubensis*, a seral deep water species occupying consistently after the third sample occasion and the pioneer algae *Udotea* sp. disappearing at the same time. Furthermore, where the species replacement trend was not observed the more widely observed successional trend of change in abundance of common species over time was also observed at both depths. Although only sampled over a period of four years, the successional trends at Rackham's were clear.

The difference in communities at 5m and 10m was supported by the results of the diversity index, where diversity at 5m was consistently higher than that at 10m with the difference increasing with continued succession. Communities in deeper waters are expected to be less diverse resulting from the reduction in light, temperature and nutrient levels, especially adjacent to a major land based source of stress. As succession proceeds, species diversity increases initially due the colonization by new species. However, as competition increases and environmental conditions begin to stabilize, diversity will decrease as the original pioneer species are displaced (Huston, 1994).

The success of coral reef communities in close proximity to the Kingston Harbour is documented as being low (Mendes, 1992; Miller 1996). Even without the additional human disturbance of vertical cutting of the reef structure, these areas have low coral cover and high fleshy algae density due to the environmental conditions of an estuarine impacted coral reef. Rackham's Cay is only 1.2km from the entrance to the eutrophic Kingston Harbour and receives high sediment load, industrial chemicals, fresh water and sewage at least occasionally (Miller, 1996). The Kingston Harbour's environmental conditions and the documented ships propeller wash (Gayle et al., 2005) stunted the areas average coral cover (6-10%) recovery and normal succession that would be expected in 4-6 years (Ohba et al., 2006).

The poor colonization, of coral reefs on Rackham's Cay new vertical substrate may be an indicator that more careful planning and mitigation should be a part of future projects of this nature. The area would be more likely to show coral colonization if parent material was installed there following the completion of dredging. This is particularly true for species such as *Acropora palmata* which reproduces significantly better asexually (from fragmentation) and shows lower colonization from spawning activities. This would also move the succession process much further ahead by enriching the community with this seral species.

A number of recommendations can be derived from the current study. Without pre-dredging base line data, while the dramatic cut face produces opportunities for the study of primary succession, the expectations for recovery will be unknown as existed in this current study. Coral recovery rates are highly variable and difficult to explain when the benchmark to original community structure is unknown. With the knowledge that a dramatic cut face was to be undertaken a coral nursery using fragments from the impacted area should have been created. This would have facilitated accelerated succession by the re-introduction of coral from a created nursery or neighbouring coral community. The time and effort applied to the current study would have yielded more compelling results if a standard monitoring programme was implemented and this should proceed longer than 5 years as currently stipulated by the National Environment and Planning Agency (NEPA).

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RESUMEN

Sucesión primaria de una comunidad de coral y algas en el nuevo sustrato vertical en el Cayo de Rackham, Puerto Royal, Jamaica. La industria de transbordo en Jamaica es de las mas grandes en el Caribe con el 90% de las actividades de tránsito que ocurren en el puerto de Kingston. El canal oriental de la bahía está poblado de un fragmento y franja de arrecife de coral. En el 2002, aproximadamente el 20% de una cara del Cayo Rackham fue cortado verticalmente a 18m y dragado para facilitar la ampliación del canal. Los cambios sucesionales en la pared de piedra caliza vertical se evaluó entre el 2009 y 2012 en 5m, 10m y 15m de profundidad usando fotografías bianuales en cuadrantes de $1m^2$. Las fotografías fueron analizadas usando "Conteo de Puntos de Coral". A 15m de profundidad, no se observó ninguna colonización de especies coralinas o algas. Las algas calcáreas y carnosas dominaron inicialmente los 5m de profundidad y mostraron una disminución gradual en el tiempo. Algas calcáreas dominaron los 10m de profundidad y también mostraban un incremento gradual en los 4 años. Corales pétreos en 5m y 10m de profundidad mostraron un % de cobertura bajo y lenta colonización, con la menor profundidad y teniendo la mayor cobertura coralina (4.1% máximo en 2011). *Sidera Siderastrea* que dominaba Cayo Rackham antes del dragado fue la especie coral constantemente presente aunque en bajo % de cobertura. La colonización por especies de los géneros *Acropora* y *Scolymia* son indicación de sucesión más lenta pero mejor a 10m de profundidad. Los diez años siguientes después de las dragas, la colonización de coral y reclutamiento ha sido lento pero exitoso en 5m y 10m de profundidad con especies previamente descritas como siendo abundantes en la zona. Recomendamos limitar las actividades de reubicación de coral a profundidades no superiores a 10m.

Palabras clave: Cayo Rackham, nuevo sustrato vertical, colonización, coral, sucesión.

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