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Coastal marine activities and coral cover at three tropical coral reefs around an oceanic island, Mauritius

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Abstract

The oceanic Island, Mauritius, is surrounded by coral reefs and the resources thus available contribute to both the local and national ecology and economy. However, the relationship between coral marine resources use and coral cover is sparse. This study used mapping and verification survey tools to determine the marine resources mainly coral reefs, their uses and their relationships at three selected coastal sites namely Belle Mare (BM), Flic-en-Flac (FEF) and Grand Baie (GB) around Mauritius Island. Selected Global Positioning System (GPS) coordinates was prepared using images from Google Earth, which was geo referenced using the software, Arc GIS. Marine verification surveys were conducted at selected GPS coordinates at the three selected sites using a 1m x 1m quadrat. Percentage of live (LC) and dead coral (DC) cover and other relevant invertebrate organisms/features were recorded and these data were treated to generate appropriate maps. Maps showing the status of coral reefs, in terms of live and dead coral cover, were produced using Arc GIS software. Data, such as annual fish catch and number of leisure crafts and fishing ships, were obtained from local sources. Density of buildings in the respective coastal area at each study site was determined using Google Earth grids images 2009. The highest percentage of LC cover was recorded at BM (45%), followed by FEF (4%) and GB (1%). Percentage LC cover was significantly negatively correlated with density of buildings (r=-0.972) and boating activities (r=-0.629) while percentage DC cover showed significant strong positive correlation (r=0.961) with boating activities and (r=0.901) with density of buildings. The use of GIS to map marine resources may, therefore, be considered as an important tool to assess the status of coral reefs and coastal marine resources use around an oceanic island to promote conservation and management of coral reefs.

Keywords: Coastal activities, Coral reefs, GIS, Mapping, Marine resources, Mauritius

INTRODUCTION

Coral reefs are extremely diverse and productive marine ecosystems [1], providing both habitat and refuge for a wide number of species including fish, invertebrates and algae. Along with their ecological importance, they provide multiple goods and services, including protein provision, coastal protection, erosion control, biogeochemical cycling, and recreational and tourism services [2]. For instance, in terms of ecosystem service values, they are considered to bring about USD 6, 045 per hectare per year [3]. The Natural Ecosystem Service Product of coral reefs ecosystem for Mauritius has been estimated to be about USD 4935.65 [1] indicating that Mauritius as an oceanic island surrounded with some 87,000 hectares of reefs [4], may generate a significant amount of revenue yearly based on coastal activities linked to its coral reefs. These features have made coral reefs possess unique characteristics to be one of the most high-profile marine systems in terms of management and conservation [5].

However, a large proportion of coral reefs are facing imminent danger of collapse due to various reasons such as anthropogenic factors [6,7], mass coral bleaching event in 1998 [6] linked to global warming, natural disasters, pollution and sea level rise. With increased anthropogenic and natural pressures on coral reefs, it has become important to manage, protect and conserve these coral reefs from further degradation. There is a need to have large scale coral reef management, rehabilitation and shore protection activities [6,7].

In order to study and thoroughly understand the spatial characteristics of coral reefs or to study the zones where the reefs are more under stressed, and to assess proposed management steps, coral reef geographic information system (GIS) is considered to be an adapted tool with a cartographic approach that is essential to the implementation of coastal zone management [8]. Reef GIS can be used quite accurately to map the reef in specific areas and to check the reef status in different regions. Based on the mapping exercise conducted, protection measures can be taken and also specific areas can be spotted where there is need for coral reef restoration or conservation and preservation.

Maps are considered to be important tools that can be used to understand the spatial dynamics and the general distribution of ecosystem [9]. GIS is used to analyse transformed data obtained by satellite, airborne, ground and undersea sensors. Examples of data that can be obtained by remote sensing are: temperature, current velocity, wave height, chlorophyll a concentration and land and water use [10]. Resource managers and scientists rely heavily on the maps to come up with management plans [9].

Since the late 1960s, submerged features, seabed composition and the bathymetry have been able to bed detected by aerial and space-borne photographs and after then the Landsat data became available in the mid 1970s. A number of experiments have been performed in order to explore the efficiency of remote sensing in coral reef science and management [11]. Ever since, studies have shown the importance of remote sensing to provide baseline information on coral reefs [8]. Coral reefs mapping by using remote sensing technique provides useful data on its configuration such as its localization, bathymetry and its geomorphologic structure. Moreover at the ecological level, information about the dominant reef communities, benthic habitats or bottom-types can be obtained by remote sensing [8]. Remote sensing techniques can be very useful to obtain data in remote areas such as St. Brandon, Republic of Mauritius, where 100 % ground-truthing is difficult [12] or other physical constraints such as shallow reef crests and reef flats [13] are prevalent.

In 2004, Turner and Klaus [12] made a case study on coral reefs of the Mascarenes, including Mauritius, to show how GIS reef-habitats maps can help to formulate and demonstrate Marine Protected Area boundaries. Mascarene reef habitats were mapped using satellite remote sensing and the ground-truthing was conducted in collaboration with the University of Wales Bangor, University of Mauritius, Shoals Rodrigues and the Mauritius Institute of Oceanography [12]. In 2003, the Mauritius Oceanography Institute (MOI) [12,14] under the Commission de L'Océan Indien (COI) started a project to map the shallow ecosystem of the Mauritian coastline, more specifically, the South-Eastern coast (Blue Bay – Grand River South-East). Using GIS supported by field-based verification, the MOI's report revealed the most prominent marine biotopes and helped to identify reef habitat according to their ecological richness [14].

Coastal people are highly dependent directly or indirectly on the coastal resources such as fishing, research purposes and planning of leisure activities. These anthropogenic activities along with global stressors related to climate change have been predicted to increase in frequency and intensity [15] and islands like Mauritius are not spared [16]. Continued mapping of coastal marine resources using GIS can help to study marine biodiversity and to better understand how the resources vary spatially and temporally. Ultimately, coastal marine regions can be compared and better managerial solutions can be taken into consideration in order to sustainably use marine resources. It is noteworthy that research works combining mapping of coral reefs and their associated resource use are limited especially in oceanic island and/or small island developing states' context. This study uses coastal areas of Mauritius Island to understand whether trends in coastal development in terms of increasing building densities and coastal activities may reflect the trend in impacts on coral reefs. Thus, the objectives of this study included mapping live and dead coral cover at three sites with different coastal development trends: Grand Baie, Flic-en-Flac and Belle mare around Mauritius Island, an island inspiring to become a sustainable island and a world leading example of an "ocean state" through properly managing its ocean and/or coral reef health, and to correlate them with coastal marine activities such as boating, fishing, and coastal development in terms of prevailing density of buildings. These sites were chosen because they vary in terms of coastal activities such as boating activities (leisure crafts and fishing boats) and annual inshore annual fish catch, and density of buildings. GIS was employed to demonstrate spatially the various reef geomorphologies and their ecological communities. Ground-truthing exercise was another objective of this study to identify and verify the reef habitats and their state.

MATERIAL AND METHODS

SITE DESCRIPTION

Three study sites (**Figure 1A**) were selected based on the levels of coastal marine activities (annual fish catch and boating activities) and coastal development (density of buildings). The first study site was Flic-en-Flac (FEF) (**Figure 1B**) that is found in the west of Mauritius. It extends from the landing station from the north of Villa Caroline to the north side of Tamarin Bay. The presence of fringing reefs, average distance of 500m from the shore, acts as a protection against waves. The coastline of FEF has undergone much developmental modification during the last decade. Extensive housing constructions have been done in this zone during the past few years [17]. The second study site was Grand Baie (GB) (**Figure 1C**) found in the north of Mauritius. . The bay is protected by direct waves; however wave diffraction occurs into the bay [17]. The bay is surrounded by small pocket beaches and rocky outcrops and the reef is found outside the bay [17]. This area has experienced rapid growth over the past 27 years and supports a variety of land uses such as residential, commercial, and recreational development [17]. This heavy pressure in developing the land is a result of the recent increase in tourism and other activities such as construction of hotels and shopping malls, boating and fishing activities in coastal areas [17]. Belle Mare (BM) (**Figure 1D**), the third study site, is located on the North-East coast of Mauritius, extending from Valtur Hotel in the north to south of Surcouf Hotel. It is surrounded by corals, sandy beaches and fringing reefs. The reef is found about 850m from the shoreline and has one well-developed pass and two blind passes. The coastal soil is very sandy and it has very poor sediment retention properties [17]. BM can be considered to be the least developed site compared to FEF that is currently undergoing rapid development and GB that can be considered as a fully developed area.

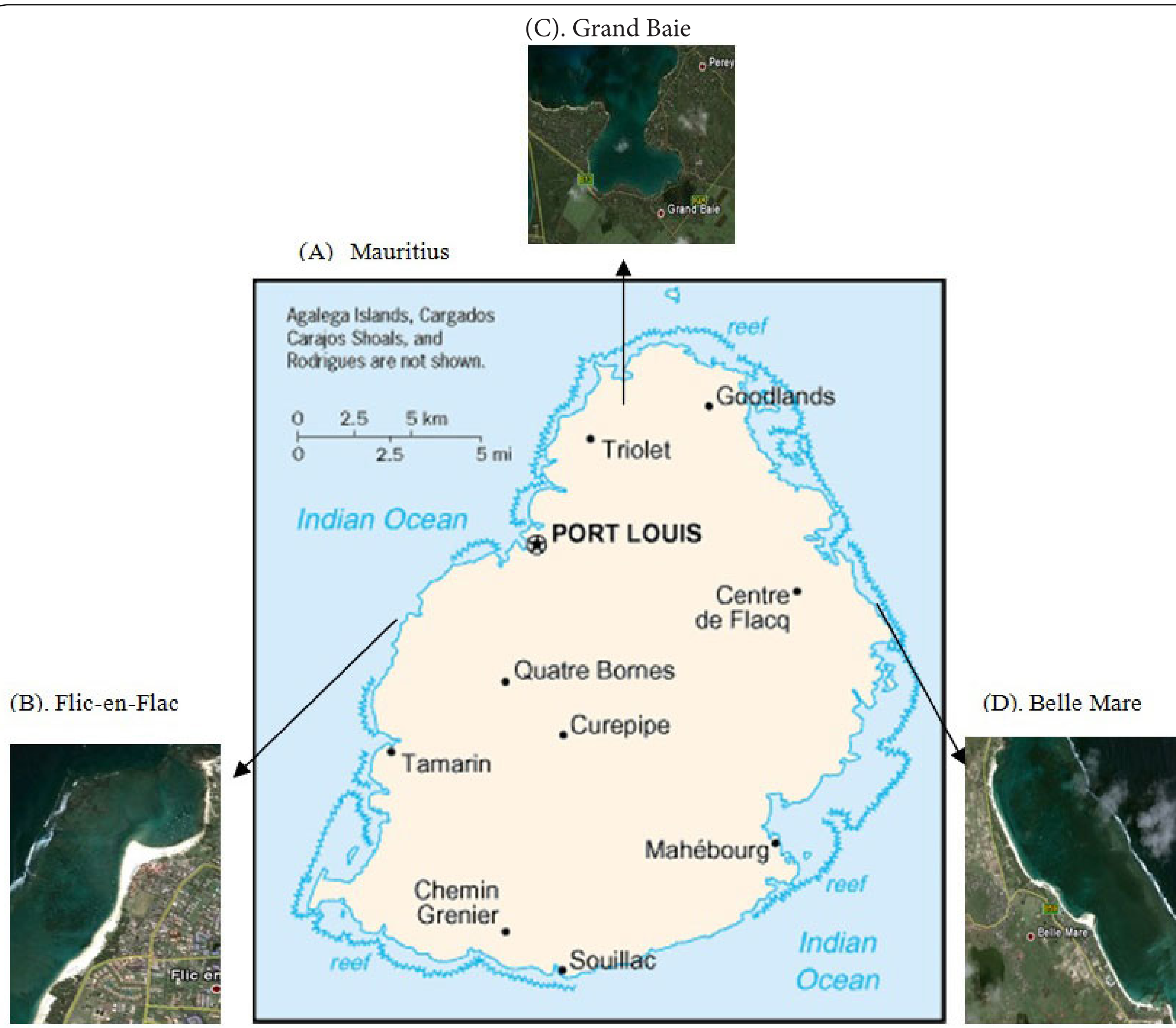

Figure 1. (**A**). Map (Source: http://www.exoticmauritius.com/maps.html) of Mauritius showing the location of the study sites namely Flic-en-Flac (**B**), Grand Baie (**C**) and Belle Mare (**D**). (Source: Google Earth)

PROCEDURE IN THE MAPPING PROCESS ACQUISITION OF THE IMAGE

Black and white aerial photographs at scale of 1:10000 were bought from the Ministry of Housing and Land. These photographs were obtained during a flight survey during 1999. The images were compared with those of Google Earth and the most reliable ones were selected. Google Earth images in the year 2009 were chosen as the different patterns at sea was reasonably visible.

In order to have a good resolution image of a particular site, different print screens were taken at the same altitude level and each print screen should have a little overlap of each other. Then these pictures were first edited individually in the software Paint to remove unwanted areas. The different images were then stitched together using the software Photoshop to give a whole view of the entire site. Two very important criteria considered included: all the pictures were print screen at the same altitude level and the next pictures were have an overlapping part of the previous one.

GEOREFERENCING

Georeferencing is the step whereby rectified values of latitude and longitude are assigning to points or pixel on a digital image on a map. Points or pixels are geoferenced to a system of Geographic Coordinates or to a projection system such as Universal Transverse Mercator (UTM). The software ARC GIS 9.2, available at MOI, was used to georeference the images. This was done by using the shape file roads, coastline and buildings of Mauritius bought from the Ministry of Housing and Land (MOHL). These maps were based on the Geodetic System 1984 (WGS 84) projection and it was used to assign coordinates on the stitched image of the sites. The process of georeferencing was done by joining three reference points on the image of Google Earth to the corresponding points on the maps that were bought from the MOHL, which already have coordinates.

Before going for ground-truthing, a number of representative GPS points were selected. This was done by drawing transects lines from shore to reef. Along each transect several points were selected and their GPS points were exported in an excel sheet from the Arc GIS. This was done on Google Earth. The distance between the two transects was approximately 15 m.

GROUND-TRUTHING

The field survey was carried out by snorkeling. During the survey, a GPS and a 1mx1 m quadrat were employed. At different pre-defined GPS points for habitat types identification and verification purposes, the quadrat was deployed, and the observation was made in situ was recorded on a data sheet. During the survey, a number of GPS coordinates were checked in each study sites (Grand Baie-325, Flic-en-Flac-135 and Belle Mare-210) along with the quadrat-based quantification. Though the main aim of this study was to compare the differences between live and dead coral cover at the three sites, the percentage of other marine features, such as macroalgae, coral rubble and sand, was also recorded using quadrat method and included in the maps.

PROCESSING THE MAPS

The maps were prepared using the software Arc GIS 9.2. Different excel sheets containing data (GPS points) for different marine resources/features were imported in GIS. The data obtained was overlaid on the georeferenced images and interpolated. The generated polygons were further digitized to give them a nicer shape by using the patches in Google Earth image as reference. The various marine resources, including the biotic components, were represented by different polygons of colours. Different layers such as roads, buildings and coastline of Mauritius, were added to the map. These layers, which are in the form of shapefile, were brought from the MOLH. The shapefile buildings were updated by editing it and using the image from Google Earth 2009. A shapefile was created for the hotels present at the study sites and was added as a layer on the map. From the attribute table, the area of the different polygons, representing the different marine resources, including the biotic components, was noted. Then, the legend, title and scale were added and the print size was adjusted to A4. The same methods were used for the three study sites.

DENSITY OF BUILDINGS

The number of buildings at the different study sites was enumerated through the use of Google Earth. These comprised drawing different zones (0-100m, 100-200m, 200-300m, 400-500m) starting from the coastline and the number of buildings within each zone was quantified. The density of buildings in the different zones was calculated using the area of the study region and the number of buildings found there. The density of buildings (m^{-2}) was further used to test any possible correlation with the percentage of coral cover (live and dead).

ENUMERATION OF LEISURE BOATS AND FISHING BOATS

The number of leisure boats at the study sites was obtained from the Tourism Authority and the data on fishing boats were obtained from Albion Fisheries Research Center (AFRC). Same data was further used to test any possible correlation between number of boats and percentage of live and dead coral cover.

INSHORE FISHERIES DATA

The annual fish catch in the lagoons at the three study sites was obtained from the Albion Fisheries Research Centre reports.

DATA PROCESSING AND ANALYSIS

All the maps were processed using the software Arc GIS 9.2 to display the habitat types and spatial distribution of live and dead corals at the three studied sites around Mauritius Island. The ground-truthing was done using in situ quadrat method. Figures for density of buildings, boating activities and annual fish catch were prepared using Excel spreadsheet. Correlations among these parameters and percentage live and dead corals were processed using SPSS software.

RESULTS

Generated maps clearly showed that the distribution of marine resources is different at the three studied sites. At Grand Baie (**Figure 2A**), underwater and exposed sand was present in a much greater percentage than the other resources. Traces of turf algae, macroalgae, and rock and boulders were also observed. The percentage of stands and patches of dead corals were 20% and 2%, respectively (**Figures 2A** and **3**). Coral rubbles tended to be more prominent near the reef area. Live coral was present in a very low percentage (1%) (**Figures 2A** and **3**) at Grand Baie and could be seen at some regions in the bay. Hotels were found near to the shore and the built areas were also found close to the coastline and they both were present in higher numbers (**Figures 2A** and **4A**).

The different marine resources/features present at Flic-en-Flac are shown in **Figure 2B**. Coral rubbles were found in a higher percentage (>65% of the studied areas) compared to other resources. Near the coastline, exposed and underwater sand were present and as the distance from the shoreline increases, macroalgae and dead corals became more prominent (**Figure 2B**). Patches of live and dead corals could be found at different places in the lagoon. Live corals were found in large areas near the reef. A portion of rock and boulders could also be seen at the northernmost part of FEF. Only one hotel was found in the study area and the coastal buildings were not that

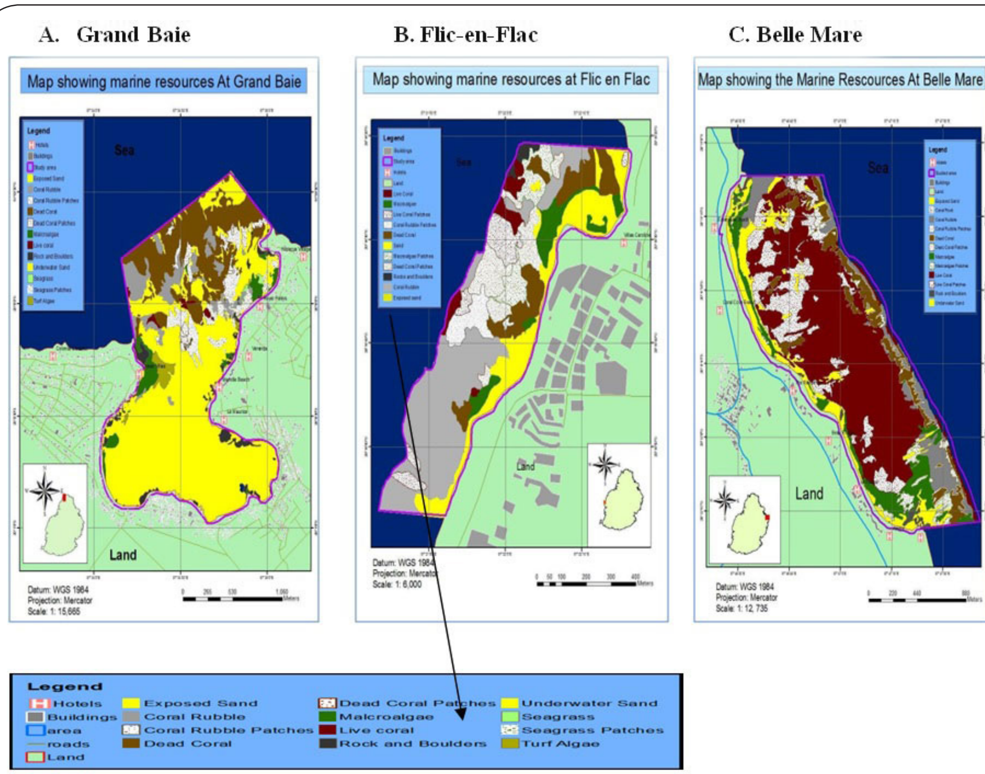

Figure 2. GIS maps showing marine resources at Grand Baie (**A**), Flic-en-Flac, (**B**) and Belle Mare (**C**). Marine resources quantified are live corals, seagrasses, sand, rock and boulders, and turf algae.

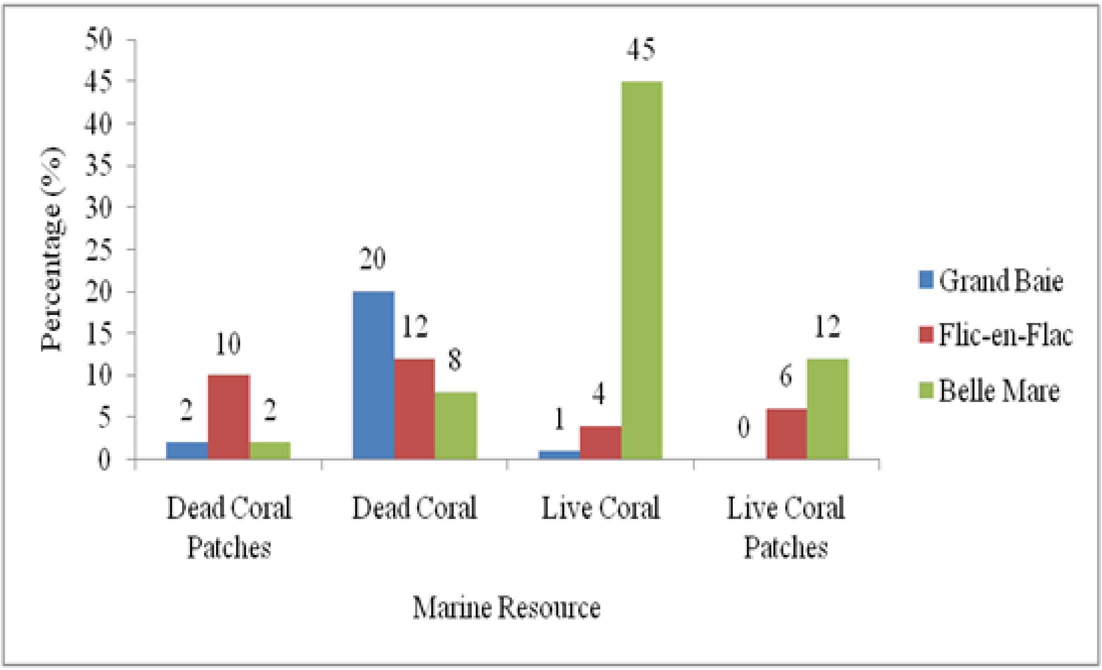

Figure 3. Percentage cover of coral (live and dead) and coral patches (live and dead). Numbers on bars represent the percentage of the coral cover.

close to the shoreline compared to GB (**Figures 3** and **4**).

Marine resources in Belle Mare are illustrated in **Figure 2C**. It is clearly visible that live corals covered a wide area of the lagoon. Near the shoreline, exposed and underwater sand could be found. As the distance from the shoreline increases, a large area of macroalgae was observed, starting from the northernmost part of BM, extending till the end of the studied area. At some places in between the macroalgal patches, areas of sand and live corals could be observed. Macroalgae were much more abundant in the southernmost part of BM and it extended nearly up to the reef area. Live corals covered most of the lagoonal water and dead corals was present in smaller quantity in the regions found near the reef. There were 7 hotels found in the study area and the built areas were very scarce and were distant from the shoreline compared to both GB and FEF (**Figure 4A**).

DENSITY OF BUILDINGS, BOATING ACTIVITIES AND ANNUAL FISH CATCH

The density of building in the different zone, 0-100m, 100-200m, 200-300m, 300-400m, 400-500m, at the 3 study sites are illustrated in **Figure 4A**. In Grand Baie, it could be observed that the building density in the zone of 0-100m was much higher compared to that of Flic-en-Flac and Belle Mare. Belle Mare had the lowest density of building in this zone (5.11E-06 m^{-2}). Grand Baie had also the highest density (9.47E-05 m^{-2}) in the second zone (100m- 200m) compared to that of Flic-en-Flac and Belle Mare. In all the different zones, it could be noticed that Belle Mare had the lower building density compared to that at the other two sites. Grand Baie had the highest density of buildings in nearly all the different zones except in the 400-500m zone, where the building density of Flic-en-Flac was higher than that of Grand Baie.

In order to compare the number of boats at the 3 study sites, a graphical representation was used (**Figure 4B**). The higher number of boats is indicative of higher boating activities in the area. Grand Baie had the higher number of boats (251 leisure crafts and 97 fishing boats) followed by Flic-en-Flac (73 leisure crafts and 2 fishing boats) and Belle Mare (33 leisure crafts and 25 fishing boats).

At Grand Baie, the annual fish catch was much higher compared to the other two sites, while in Flic-en-Flac the annual fish catch per kg was comparatively lowest that the other areas (**Figure 4C**).

CORAL COVER AND PREVALENT COASTAL ACTIVITIES

Building density had the highest negative correlation (r=-0.972) with the percentage of live coral compared to the number of boats (r=-0.629) (**Table 1**). This implies that if building density increases, percentage of live coral decreases. All the three factors, that is, the number of boats, building density and the annual fish catch, have

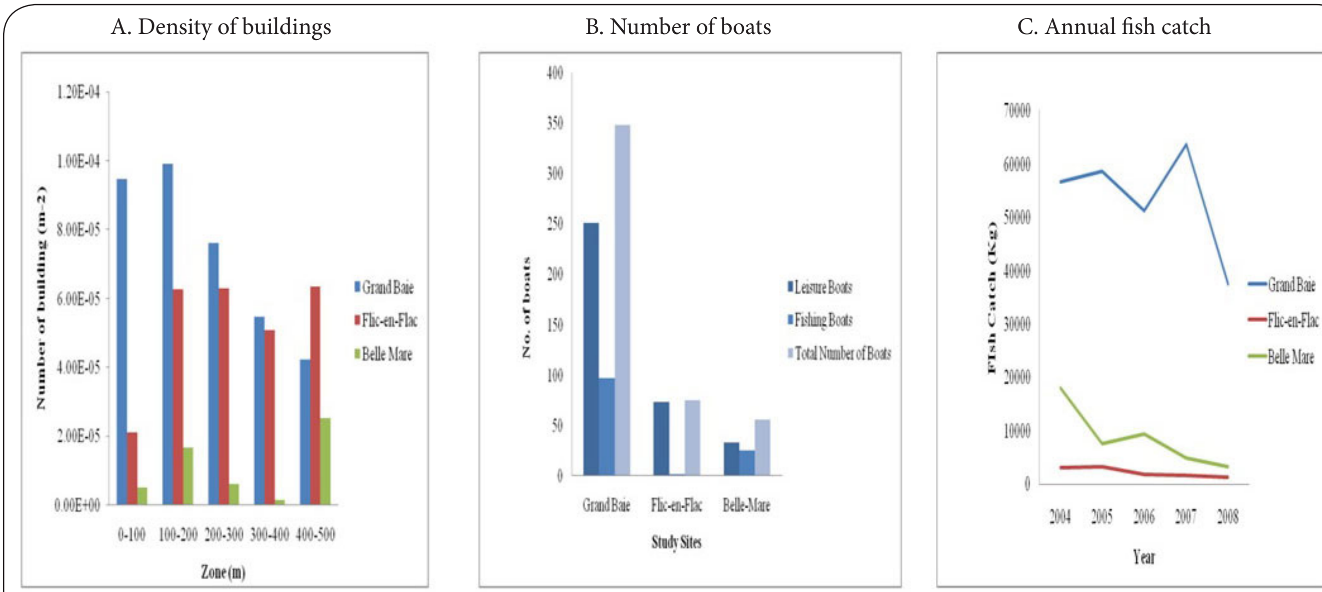

Figure 4. Density of buildings (**A**), number of boats (**B**): Annual Fish catch (kg) (**C**) at the 3 study sites: Grand Baie, Flic-en-Flac, and Belle Mare.

Table 1. Correlation between different activities and percentage coral cover (live and dead).

	Density of Buildings (m^{-2})	Boating Activities	Annual Fish Catch (Kg)
Live Coral cover	-0.97	-0.63	-0.49
Dead Coral cover	0.9	0.96	0.93

strong positive correlation coefficient (r>0.9) with the percentage of dead coral cover.

DISCUSSION

The three targeted study sites around Mauritius Island included Belle Mare, Flic-en-Flac and Grand Baie and have been developing at different rates and to different extent since 1990 [18,19]. Statistics Mauritius, operated under the Government of the Republic of Mauritius, employs the Relative Development Index (RDI) as a composite index to gauge the relative achievement of sub-regions of the country in dimensions of development derived from housing and population censuses [20]. The RDI values range from o to 1 indicating least to highest development. The RDI values were obtained from the Statistic Mauritius for 1990 and 2000 [18] and 2010 [19]. The values for Belle Mare were ≤0.499, 0.5455 and 0.6535 for the years 1990, 2000 and 2010, respectively. In case for Flic-en-Flac the RDI values were ≤0.499, 0.7242 and 0.8453 for the years 1990, 2000 and 2010, respectively. For Grand Baie the RDI values were 0.6-0.699, 0.6903 and 0.7581 in 1990, 2000 and 2010. These RDI values indicate that both Belle Mare and Flic-en-Flac started with lower values but Flic-en-Flac reached a higher value within the same 20 years time, while Grand Baie started off with a higher value in 1990 and reached a higher value that Belle Mare but lower than Flic-en-Flac in 20 years time. It is noteworthy that monitoring records of live hard coral cover at sites like Trou-aux-Biches and Albion, close to Grand Baie and Flic-en-Flac sites respectively, from years 2002/2004 to 2010 decreased by almost half (to ~20% cover) while at Belle Mare it stayed quite stable at ~45% cover [21]. These trends in rates and extent of changes in RDI values may also be possibly linked to the observed patterns in percentage live coral cover. The results obtained in this study showed that higher percentage of dead coral cover and dead coral patches was recorded at Grand Baie, followed by Flic-en-Flac and Belle Mare. On the other hand, highest percentage of live coral and live coral patches was obtained at Belle Mare, followed by Flic-en-Flac and Grand Baie. This difference was correlated to different factors studied namely, building density, number of boats or boating activities and annual fish catch at the three study sites.

Highest percentage of dead coral and dead coral patches at Grand Baie is probably because of high development activities linked to the tourist industry prevailing at this site. Grand Baie is considered to be the most developed site among the three studied sites and it has all the facilities and accommodation for tourists. Changes in shore and lagoon may bring about through the construction of tourist infrastructures an impact on the marine ecosystem, including the reef systems [22]. This might be due to changes in current flow patterns, changes in the light intensity in the water column and also by sedimentation [22].

Data obtained on fishing boats and leisure crafts indicated that Grand Baie has recorded the highest pleasure crafts and boating activities compared to the other sites investigated. Moreover, there was a positive correlation between number of boats and percentage of dead coral (r=0.961). Irresponsible boating activities and accidents may cause damage to the shore and reef environment. Anchoring of leisure crafts and fishing boats may have serious potentials impacts to the reefs and corals [6,7]. Indeed, high boating activities may also imply more impacts on corals and it may be associated with the high percentage of dead corals and dead coral patches.

In Grand Baie, there is not only a high number of fishing boats, but also the fishing boats found there are very well equipped and bigger in capacity [pers. observ.]. This may account for the high inshore annual fish catch value from 2004 to 2008 that were obtained from the AFRC [21]. Positive correlation between annual fish catch and percentage of dead coral (r=0.93) may imply that increasing annual fish catch aggravated coral death. The higher the annual fish catch may mean less of herbivorous fishes in the lagoon which favors the growth of macroalgae that may in turn disturb the marine ecosystem, including corals. Several studies have reported variation in habitats due possibly to anthropogenic interactions in non-protect areas have an influence on reef fish abundance [23-25]. Moreover, unreported destructive fishing methods or inappropriate fishing gears possibly employed by fishermen [6,26-29], may also harm the coral reef, for example gill nets, fish traps, and anchors break coral and may cause coral death through entanglement.

The trend observed in percentage of live and dead corals at Grand Baie may also be due to the fact that Grand Baie has the highest building density, meaning that the level of urbanization of Grand Baie is much higher compared to other studied sites. The building density (m^{-2}) is also more elevated in the 500m zone from the shoreline. It has been found that 60% of the world's coral reefs are threatened by human activity [30,31]. Increasing human population, including their proximity to the coast, has been causing harm to coral reefs at an extraordinary rate [32,33].

Flic-en-Flac is the second study that is much affected by anthropogenic impacts. It is one of the most intensively used public beaches in Mauritius. Moreover, the reef is now found so further from the shoreline, i.e, approximately 350 m away from the shoreline. It may be that such a situation encourages the public to choose to visit to Flic-en-Flac and the water depth in the lagoon is quite low, where temperature rise during summer can result in coral bleaching and mortality. This provides an ideal environment for snorkelers to swim to the reef. However, shallow water may also imply the corals are more exposed to damage by swimmers and snorkelers. Damage to corals can indeed be caused by snorkelers [34], which might have accounted to the result obtained for Grand Baie and Flic-en-Flac, which are more frequently visited by tourists.

Furthermore, it can be deduced that the number of leisure crafts was considerably higher in Flic-en-Flac compared to Belle Mare. It is possible that due to the low water depth, the corals may be more affected by the boating activities and temperature rise. The mean annual fish catch in Flic- en-Flac is in fact lowest among the three sites. The low annual fish catch inshore may be due to the low water depth and the fact that there are only 2 fishing boats in that region. There has been extensive construction works taking place at Flic-en-Flac during the past years. These constructions are taking place close to the coastal areas. Moreover, the building density (m^{-2}) at Flic-en-Flac is much higher compared to Belle Mare. This may indicate that the coastal population density of Flic-en-Flac is higher than that of Belle Mare but less compared to Grand Baie. The deterioration of corals in the lagoon of Flic-en-Flac may be due to the degradation of the lagoon water quality due possibly to hotel sewage, direct fresh water runoff and agriculture and infilling of wetlands [17]. This report highlights the possible links of degradation of corals to human activities. It is, therefore, proposed that the more the construction works in the coastal zone, the greater might be the level of degradation of corals around oceanic islands.

Belle Mare is the study site that seems to be the least affected by human interaction. The ratio of live coral and live coral patches to dead coral and dead coral patch is nearly 6:1. This may be explained by the fact that not only the building density (m^{-2}) is low but the boating activities are also lesser compared to the other two sites. However, there was some extent of coral destruction observed at Belle Mare. This may be due to the influx of fertilizers from nearby agricultural field and discharge of sewage at this site [35]. Coastal coral reefs are at risk with increasing runoff of nutrients, sediments and pollutants and can result in coral degradation [36]. Increasing nutrients in coral reef ecosystem encourages a shift from nutrient-poor environment occupied by symbiotic dwellers, such as corals to nutrient-rich and macroalgal-dominated environment [36]. Moreover, high input of nutrients may cause harm to corals by the promotion of phytoplankton, as well as, seaweeds which compete with corals for space on the reef. Some 435 species of macroalgae have been documented to be distributed around the Mauritian coast [37]. A high diversity and high nutrient levels might contribute to higher percentage of macroalgae recorded at Belle Mare.

It is noteworthy that the reef at BM is about 1 km away from the shoreline. Since the water depth is high in Belle Mare, though not uniformly throughout the site, the corals are less exposed to damage caused by snorkelers and temperature rise during low tide. Dead corals are located near the reef. This may be because at some point in the past, parts of the reef were broken to allow for flow of water inside the lagoon to decrease the effect of excess nutrients. Moreover, there are also some people who may break the reef illegally to make passage for boats. This could be another possible reason for the concentration of dead corals near the reef. Mean annual fish catch during 2004 to 2008 is higher at BM than that at Flic-en-Flac but less than at Grand Baie. This can be explained by the fact that in Belle Mare there are more fishing boats compared to Flic-en- Flac and also that the presence of the live corals reefs enhance the growth and occurrence of fish.

The correlation coefficients showed that there were indeed a negative relationship between the building density and the percentage of live corals. Building density and boating activities had the highest effect on live coral cover, which is reflected by their correlation coefficient of -0.97 and -0.63, respectively. The correlation coefficient value between annual fish catch and live coral was lowest (r=-0.49) implying that corals were possibly affected to a lesser extent. Correlation coefficient between percentage of dead corals and the other three factors is very high. Nearly all the value was about 0.90. This may imply that there was a strong relationship between the building density, boating activities and annual fish catch and the percentage of dead coral. Anthropogenic impacts have been shown to cause coral death and thus may account for the observed strong correlations in the present study. However, if one were to have a thorough understanding, identify and establish causal relationships between the studied parameters and coral reef status, further in-depth studies with larger sample size and robust statistical analyses would be required.

It is noteworthy that in recent years ocean warming possibly related to climate change may also affect live coral cover for instance through severe coral bleaching and subsequent mortality. Several reports have documented spatial, including coast-reef scale, and temporal variations in coral bleaching [38,39], coral colonies acclimation potentials on reefs [40], and predation on corals [41] at Flic-en-Flac and/or Belle Mare. Recurrent events of bleaching-linked mortality of corals have also been predicted on Mauritian reefs [16]. These recent reports imply that future mapping studies need to be conducted and compared to previously set baselines. For a more thorough understanding of changes of coral cover evaluated through mapping exercises on regular intervals, detailed assessment of extended spatial coral bleaching extent and associated mortality along with physic-chemical parameters such as sea surface temperature and nutrients among others need to be undertaken.

CONCLUSION

GIS mapping of marine resources/features at the three study sites revealed that highest live coral and live coral patches were recorded at Belle Mare, followed by Flic-en-Flac and Grand Baie. However, highest percentage of dead coral and dead coral patches was observed at Grand Baie, followed by Filc-en-Flac and Belle Mare. Density of buildings and number of boats were highest at Grand Baie, followed by Flic-en-Flac and Belle Mare, while annual fish catch was highest at Grand Baie, followed by Belle Mare and Flic-en-Flac. Correlation analysis showed that the different factors studied, such as building density, number of boats and annual fish catch may have a negative impact on live coral cover. GIS mapping may be used to provide data on the status of corals and other marine resources/features around oceanic islands. Changes in coral reef habitat features detected through GIS mapping exercises may ultimately help in strategizing sustainable coastal development along with appropriate management, conservation and any rehabilitation required. However, further in-depth studies with larger sample size and statistical analyses are warranted to identify and establish any causal links between targeted coastal activities and coral reef health status mapped through GIS tools.

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