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Coastline artificialization and land use changes in coastal cities - Implication for coastal management in Noumea (New Caledonia)

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Abstract:
The 160 km length coast of the Noumea peninsula (New Caledonia, South-Pacific) is constituted by successive bays of various natures: beaches, cliffs, mangroves and artificial segments. This coast has known profound changes in past decades, in relation with the economic development linked to the presence of the American army during the Second World War and to the "nickel boom" between 1970 and 1975. Growing urbanization and therefore the artificialization of the coastline stems from these two prosperous periods. Indeed, it is at this time that the embankments, the only possibilities of extension of this territory, have developed considerably. The work carried out consisted in retracing the position of the coastline, the coastline nature changes and in characterizing and quantifying the evolution of the land use of the coastal strip from 1935 to 2016. This study shows:

- A very strong artificialization of the coastline, particularly during the 1954-1985 period. The evolution of land use during this same period shows a very strong expansion of urban (built and urban fabric) and artificialized areas (trade area, communication routes and harbour area) especially at the expense of forests;
- The surface of embankments increased very strongly between 1954 and 2016. Between 1954 and 1985, their area increased by a 9.4 factor and between 1985 and 2016 by a 1.3 factor. These embankments are responsible for spectacular advance of the coastline in the concerned sectors;
- The backfills have largely participated in the modification of the coast by closing some bays and decreasing or even annihilating some inter-bay connections. The modifications of the hydro-sedimentary exchanges induced have very likely consequences on the physical functioning and the current dynamics of the littoral, on the water quality and on the ecosystems.

This inheritance induced by human actions will have to be taken into account when making decisions concerning the management of the Noumea coastal area.

Keywords: Coastline changes, Coastal urbanization, Anthropization, Artificialization, Embankment, Coastal environment, Coastal ecosystems, South-Pacific, New-Caledonia.

Résumé:
Le littoral de la presqu'île de Nouméa (Nouvelle-Calédonie), long de 160 km et découpé en baies successives, est de nature très variée ; des plages, des falaises, des mangroves et des côtes artificielles s'y succèdent. Ce littoral a connu au cours des dernières décennies de profondes mutations, dues principalement au développement économique lié à la présence de l'armée américaine, pendant la seconde guerre mondiale, puis au « boom du nickel » entre 1970 et 1975. L'urbanisation croissante et donc l'artificialisation du littoral découle de ces deux périodes « fastes ». En effet, c'est à cette époque que les remblais, seules possibilités d'extension de ce territoire, se sont considérablement développés. Le travail réalisé a consisté à retracer la position du trait de côte, l'évolution de sa nature et à caractériser et quantifier l'évolution de l'occupation du sol de la frange littorale de 1935 à 2016.
Il en ressort :

- une très forte artificialisation du trait de côte notamment au cours de la période 1954-1985. L'évolution de l'occupation du sol au cours de cette même période montre une très forte expansion des surfaces urbaines (bâti et tissu urbain) et artificialisées (zone de commerce, voies de communication, zone portuaire) surtout au dépend des forêts ;
- la surface des remblais a très fortement augmenté entre 1954 et 2016. Entre 1954 et 1985 leur surface a augmenté d'un facteur de 9,4 puis d'un facteur 1,3 entre 1985 et 2016. Ces remblais sont responsables d'une avancée spectaculaire du trait de côte dans les secteurs concernés ;
- les remblais ont participé très largement à la modification du littoral nouméen en fermant certaines baies et en diminuant, voire annihilant, certaines connections inter-baies. Les modifications des échanges hydro-sédimentaires induites ont très probablement des conséquences sur le fonctionnement physique et la dynamique actuelle du littoral, sur la qualité des eaux et sur les écosystèmes.

Cet héritage induit par les interventions humaines devra être pris en compte lors des prises de décision concernant la gestion de l'espace littoral de Nouméa.

Mots-clés:
Trait de côte, Occupation du sol, Anthropisation, Artificialisation, Environnement littoral, Écosystèmes côtiers, Pacifique, Nouvelle-Calédonie, Nouméa.

1. Introduction

In recent decades, coastal cities have grown considerably. This grown has been accompanied by an artificialization of their coastlines with strong impacts on the functioning of the coastal system and the state of the ecosystems. Our work presents the example of the Noumea city (New Caledonia, South Pacific).

2. Methods

Several steps were followed during this study (figure 1). The first task consist in realizing an inventory of aerial photos for the older period (since 1935 to 1995) and aerial orthophotography for the more recent period (since 1995 to 2016) from various dates and different sources (SHOM/IFREMER/VDN, DITTT, GIE SERAIL). Among the 1 000 photos inventoried, ten acquisition dates were selected (1935, 1943, 1954, 1971, 1976, 1985, 1995, 2007, 2012/2013, 2016) for theirs quality, homogeneity and historical interest. The next tasks were to rectify (©SAFESoftware-FME), to georeference (©ESRI-ArcGis) and to create orthomosaics from the photos (©Agisoft PhotoScan, 0.5m to 1m of resolution). Then digitalization of coastline were realized at ten dates over a period from 1935 to 2016. During this process, the nature of each coastline segment was determined and classified using a five classes typology: artificial coast, rocky coast, cliff, mangrove and beach (see GARCIN *et al*., 2018 for details). In function of coastline nature, different indicators were used: permanent vegetation line for natural beaches and segment, cliff top for cliff areas, limit of coastal structures or of the embankment when the coastline is artificial or linked to land reclamation. Digitalization was realized by the same operator to reduce human bias and ensure homogeneity interpretation. Digitalization was realized at a scale between 1:500 and 1:1000 in order to guaranty an accuracy compatible with the needs of this study. Spatial accuracy was between 0.5 and 1 meter. It depends of the quality and resolution of the initial photographs and of the geo-referencing and rectification processes.

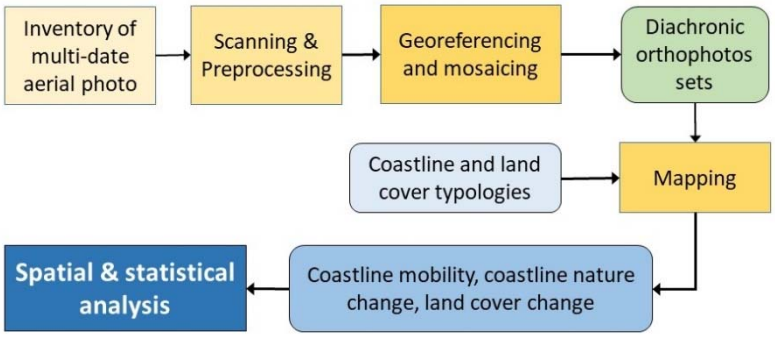

Figure 1. General method.

The coastal land cover was mapped at three dates (1954, 1985 & 2016) using an eleven classes land cover typology (cliff, rocky coast, beach, forest, agricultural land, green space, urban and building, coastal structure, industrial and public facilities, communication network: airport, harbour…). The land cove database is structured with three levels of accuracy as the Corine Land Cover Database. The classes are adapted to the tropical context of New Caledonia (GARCIN *et al*., 2018). Digitalization of the Noumea Peninsula land cover was realized at a scale between 1:500 and 1:1000 (i.e. at a largely higher resolution than the CLC database). The last step has consisted in a spatial analysis of changes between dates using GIS software (©ESRI-ArcGis) and simple statistical analysis.

3. Results

3.1 Coastline changes between 1935 and 2016

The most significant changes are observed in artificial areas where backfill were realized (figure 2): (i) around the SLN plant where coastline progradation is continuous since 1935 and reaches 2000 m, (ii) the transformation of Nouville island in a peninsula by backfilling of the neck mainly (1971-1974), (iii) the closure of the Uaré bay by backfilling since the beginning of the 80' (iv) coastline progradation induced by inert waste material dumping (Ducos). Other changes are mainly coastline progradation affecting the bays (Orphelinat +180m, Moselle) in relation with embankments and infrastructures development. On rocky coasts, coastline changes are parallel to the coast and linked to infilling for roads construction (e.g. 40m to 50 m along Sainte-Marie Bay). Few segments are detected as affected by erosion due to the high level of artificialization, the generalization of backfilling and local beach nourishments (Anse Vata 2006 & Citron Bay in 2014) after erosional events.

3.2 Coastline nature change during the last 70 years

The coastline nature was investigated at three dates: 1954, 1985 and 2016. In relation with the artificialization, the Noumea coastline length increased from 135 km in 1954 to 154 km in 1985 and 174 km in 2016. The coastline nature is highly changing during the same period. In 1954 32% of the coast was constituted by beaches while they represent 16% in 1985 and only 11% in 2016. The length of coast occupy by mangroves shows also a drastic reduction from 28% in 1954 to 18% in 1985 and 16% in 2016. The rocky segments are affected by the same evolution with a decreasing of their lengths from 30% in 1964 to 16% in 1985 and 12% in 2016. In 1954, the natural coastal segments (beach, mangrove and rocky coast) constituted 89% of the total coastline length. Their high decrease (38% in 2016) was realized at the profit of artificial and anthropogenic segments that was only of around 11% in 1954 but reaches 49% in 1985 and finally 61% in 2016.

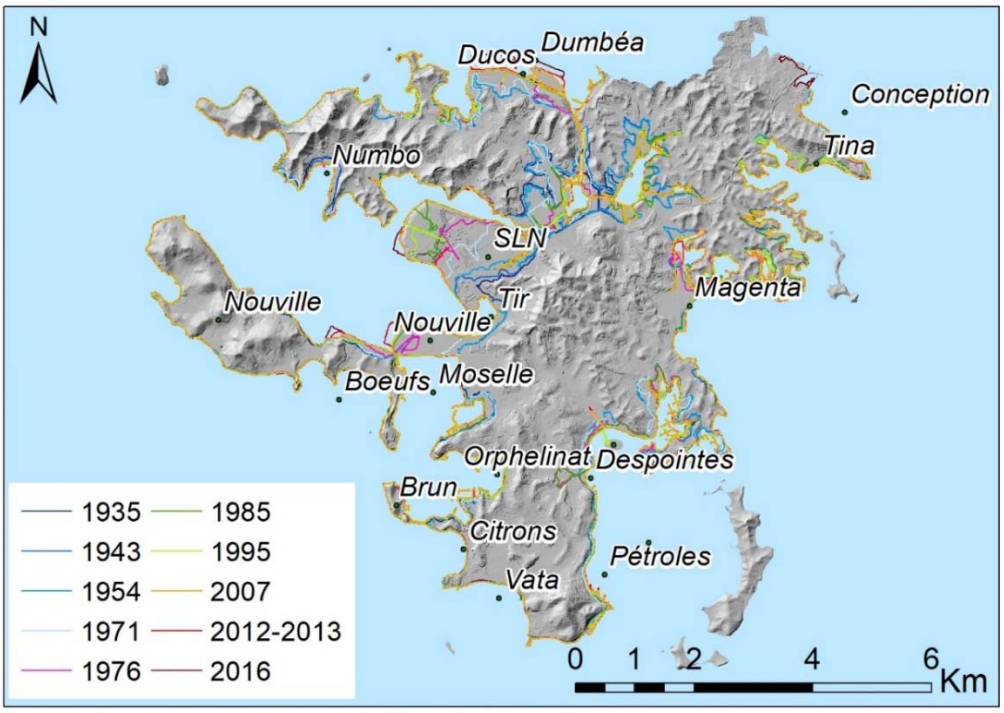

Figure 2. Coastline changes from 1935 to 2016 at city scale (Background DEM © DITTT).

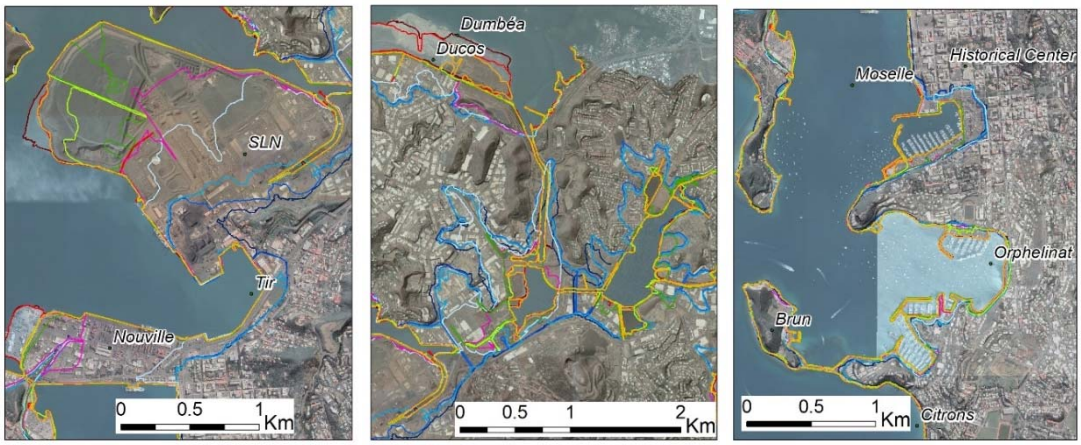

Figure 3. Details of backfilled areas – Left: SLN plant and La Nouville; Centre: Uaré; Right: Orphelinat and Moselle Bays (Background image: © GoogleEarth).

The analysis of the diachronic maps from 1954 to 2016 shows that the artificialization began mainly on the western coast at the vicinity of the historic City centre and of the Bays (Tir, Moselle, Orphelinat, Petite & Grande Anse), figure 3. This artificialization is linked to the mining trash backfill around the SLN plant as well as backfill in relation with harbour and communication networks development. In 1985, all the northern part of Noumea (Ducos, Rivière Salée…) is affected while the artificialization continues to

increase around the City centre. On the eastern part of the peninsula, the artificialization concerns mainly the coastal areas of Magenta, Port Despointes and Sainte-Marie Bay. In 2016, anthropogenic coastal segments are largely dominant, some short natural segments remains. The artificialization rate was higher in the 1954-1985 period than the following one and is directly linked to the Nickel-boom (60'-70') and to the associated urban and industrial development.

3.3 Land use change 1954-2016

The coastal land use was mapped at three dates (1954, 1985, 2016) each one separate by 31 years (figures 4 et 5). The area occupied by each type at each date was computed using GIS software (© ESRI-Arcgis). The percentages of surface of each class relative to the land surface at each date (note that the terrestrial area increase in time due to backfilling) are presented in the figure 6. In 1954, the forest is dominant (84.5%) while the built area represents only 12.4% and agricultural land 1.3%, others classes are insignificant. In 1985, we note the high increase of urban surfaces that reach 34.8% of the area while forested area decrease to 45.1%.

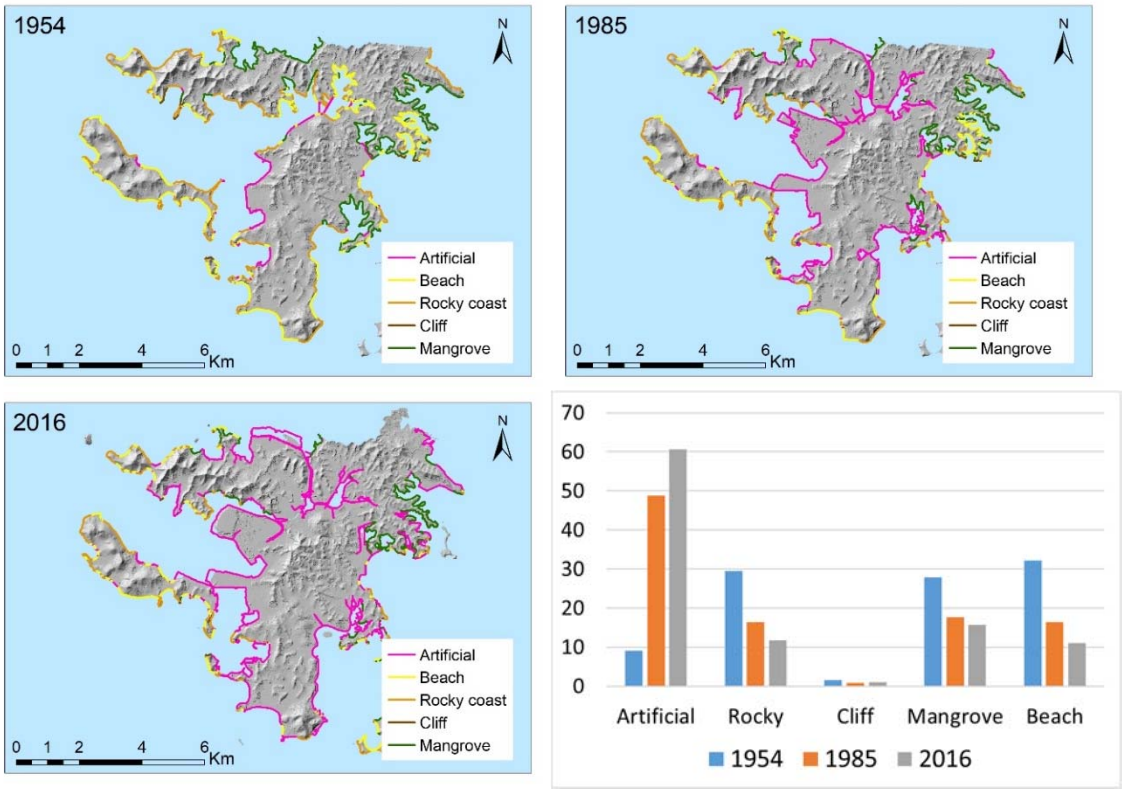

Figure 4. Coastline nature from 1954 to 2016 (% of length).

The airport, harbours and communication networks show an increase and grown from 0.4% in 1954 to 3.5% in 1985 and industrial and public facilities show the same evolution

from 0.9% to 8.9%. The area occupied by coastal structures increase from 0.01% in 1954 to 0.48% in 1985. During the same period, the agricultural surface decreases from 1.32% to only 0.44%. Between 1985 and 2016 the urban growth continue and covers 45.1% of the total area while forest are shrinking and represent only 28.38%. During this period coastal structures and facilities are expanding (respectively 0.53% and 9.87%) but more slowly than during the previous period.
The area covered by the airport, harbours and the communication networks increases to 5.7% of the total area. We have to note the increase of green spaces from 0.18% in 1954 to 9.61% in 2016 in relation with the development of the urban way of life.

3.4 Land reclamation and backfills

The Noumea city is characterized by the existence of backfills that have modelled the urban landcape, some of them were realized as soon as the XIXth century (HOFFER, 2013) but the majority were done during the XXth. The backfills were done for various reason as the infilling of humid zones for urban extension and sanitation, the construction of coastal roads, the storage of mining slags (SLN plant), storage of inert waste (Ducos dump). Sometimes the backfills were realized with both objectives: storage of mining slags and industrial, commercial or communication network development (Nouville peninsula, Port-autonome…).
The backfills were mapped at several dates (1935, 1943 et 1954, 1985 et 2016) but we present in this paper only the maps of 1935/1943, 1985 and 2016, figure 7. In 1935/1943 the backfill surfaces are present in the historical City Centre, under the Magenta airport and around the SLN Plant and in Nouville. Their total area reaches 75ha. Between 1954 and 1985, the backfills area highly increase until 703 ha in relation with the Nickel booming and the high economical and urban development of the territory. This represents an increase by a 9.4 factor in comparison with the 1954 area. In 2016, the area covered by backfill reach 937 ha that represents an increase of a 1.3 factor in comparison with the 1985 area. The increase of backfilled area during the 1954-1985 period is thus largely higher than during the 1985-2016 one, even if their durations are identical. A cross analysis between the backfilled areas and the land use map shows that they have various uses. Economic and industrial activities are dominant (SLN, Harbour…) and concern respectively 24% and 21% of the backfilled area. Mixt and public buildings occupy respectively 11% and 10% of the total area while leisure activity surface occupied 9%. Individual buildings are present on around 8%, transport near 8% while unoccupied surface are around 8% of the total area.

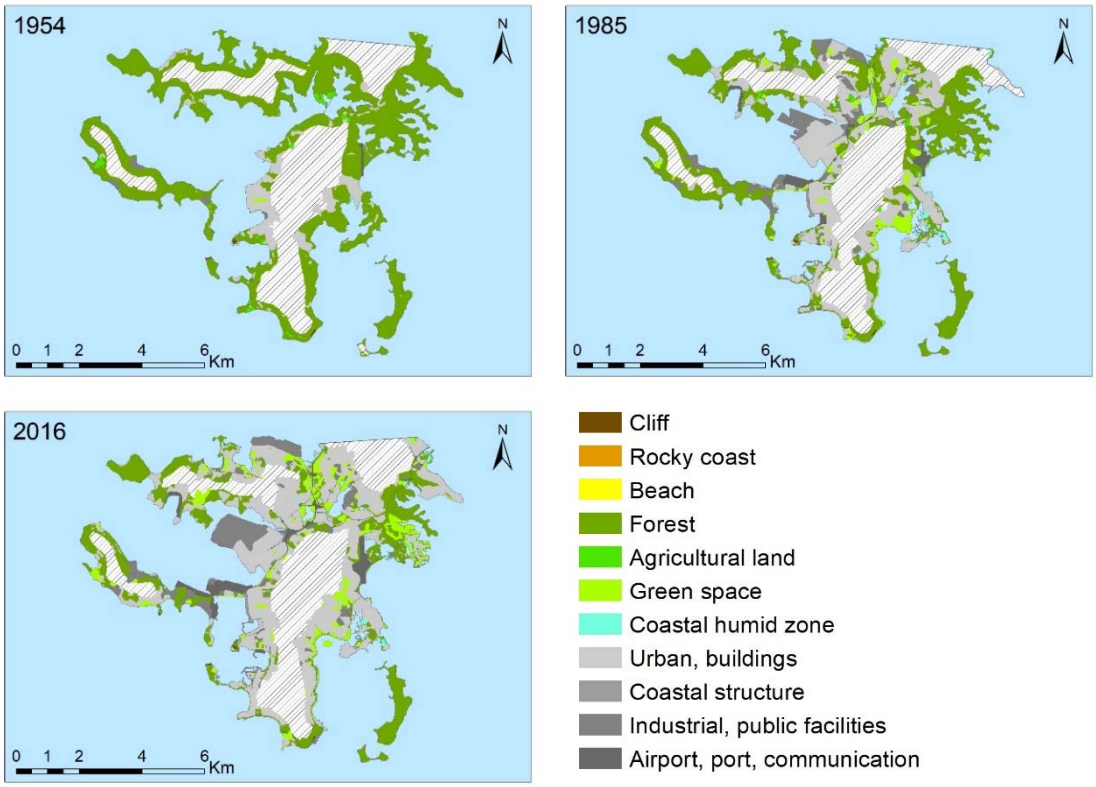

Figure 5. Land use maps in 1954, 1985 and 2016.

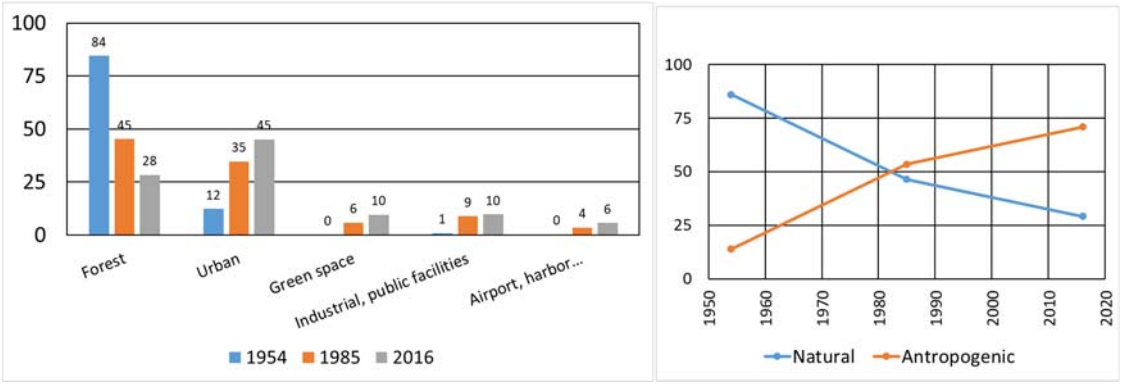

Figure 6. Left: change of main land use classes 1954-2016 (% of area); Right: natural versus anthropogenic land use areas change.

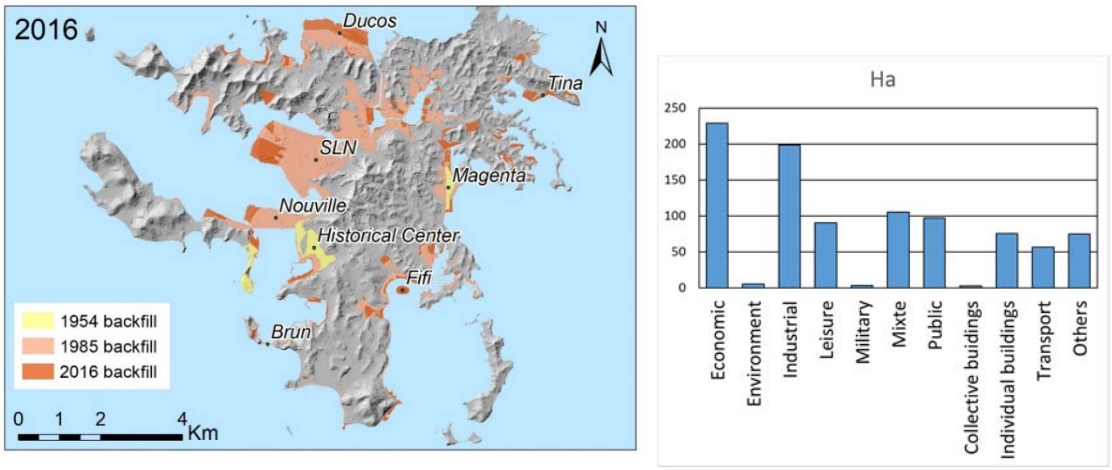

Figure 7. Left: Evolution of backfilled from 1954 to 2016;
Right: Land use of backfilled areas in 2016.

4. Discussion and conclusion

4.1 A highly impacted coastal system altering its recovery capacity

The high level of artificialization of coastal segments (sea wall, quays, rip-rap, backfills…) leads to the alteration of cross-shore processes. In consequence, the natural adaptation capability of coast to changing environmental forcing factors and to recover after the occurrence of an extreme event occurrence (cyclone or big tropical storm) is highly degraded. The backfills have modified the Noumea coast closing some bays and channels, connecting islands with the natural peninsula and decreasing or even destroying some inter-bay connections. The induced modifications of the hydro-sedimentary exchanges have very likely some consequences on the physical functioning of the coastal system (current dynamics, sedimentary transport, beaches evolution …), on the water quality and in consequence on the coastal and marine ecosystems, figure 8.

4.2 Flooding hazard and risk

The backfills are mainly done at the expense of the sea, they constitute generally low lands. In this case, the assets lying on them are today exposed marine flooding during extreme marine events (major cyclone and tropical storms).

The nature of concerned assets is various: industrial, public facilities, mix and private buildings etc., some of them are critical. In the future, due to the sea level rise, the level of exposure to flooding hazard of these assets will be higher. Decisions anticipating the future conditions must be done in order to lower the impact of sea level rise impact on people and on the society.

4.3 Implication for coastal management and ecosystem restoration

The modifications of the coastal system (artificialization, land reclamation, modification of morphologies…) during past decades have highly modified the state of the Noumea coast and its functioning. These changes constitute an inheritance entirely linked to the human actions (past and present). This inheritance must be taken into account (i) when making decisions concerning the management of the Noumea coastal area to guaranty that decisions are coherent and compatible with the actual state of the coastal system, (ii) during actions of environmental remediation in order to maximize the chances of success.

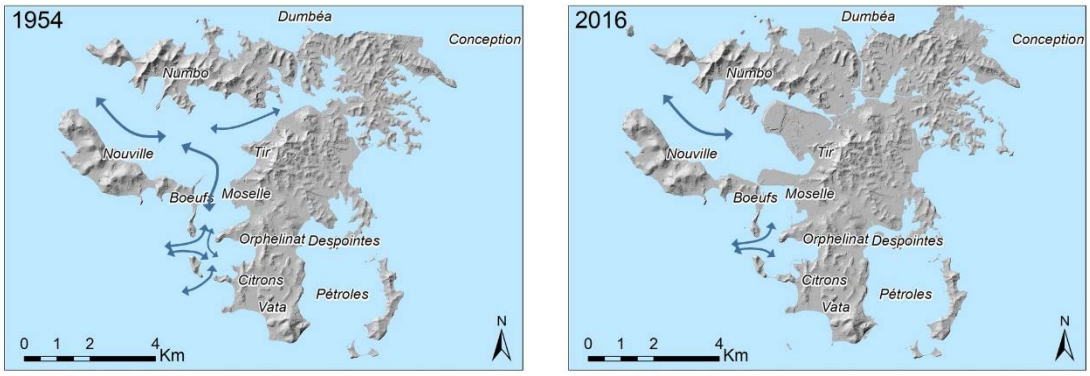

Figure 8. Schematic of hydro-sedimentary exchanges modifications between 1954 (left) and 2016 (right) due to channels closure between islands and bays in relation with backfills.

5. References

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