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IMPACT OF ANTHROPOGENIC ACTIVITIES ON THE VEGETATION STRUCTURE OF MANGROVE FORESTS IN KRIBI, THE NYONG RIVER MOUTH AND CAMEROON ESTUARY

Thesis
Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Science of the Université Libre de Bruxelles-ULB (Belgium) and University of Douala (Cameroon)

by

ADOLPHE NFOTABONG ATHEULL

Promotor: Pr. Dr. FARID DAHDOUH-GUEBAS
Co-promotor: Dr. NDONGO DIN

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IMPACTS DES ACTIVITÉS ANTHROPIQUES SUR LA STRUCTURE DE LA VÉGÉTATION DES MANGROVES DE KRIBI, DE L'EMBOUCHURE DU FLEUVE NYONG ET DE L'ESTUAIRE DU CAMEROUN

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ADOLPHE NFOTABONG ATHEULL

COMPOSITION DU JURY:

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Cover photo: A logger illegally using a chain saw to cut down large trunks of *Rhizophora racemosa* Meyer in the Cameroon estuary. The big logs would be progressively pushed on mud along a clear-felled corridor and transported towards the local markets using traditional boats. Photo taken by A. Nfotabong Atheull.

Photo de couverture: Un coupeur de bois utilisant illégalement une tronçonneuse pour abattre un arbre de *Rhizophora racemosa* Meyer dans l'estuaire du Cameroun. Les larges morceaux de bois seront progressivement enroulés sur le sédiment boueux, le long d'un corridor dévégétalisé et transportés vers les marchés locaux à l'aide de pirogues traditionnelles. Photo prise par A. Nfotabong Atheull.

À mes parents

À mes deux petits frères et à ma petite sœur

À la mémoire de ma bien-aimée Henriette Sidonie

« *Le milieu est conçu comme ressources et l'homme comme le maître d'œuvre de la transformation et de la restauration de la nature* ».

Marcel Dubois (cité in M.C Robic, 1992: Du milieu à l'environnement. Pratiques *et* représentations du rapport homme/nature depuis la Renaissance, Paris, Economica)

SOMMAIRE

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Les mangroves sont des écosystèmes intertidaux que l'on rencontre le long des côtes tropicales et subtropicales. Bien que globalement reconnues comme des écosystèmes à importance écologique, biologique et économique remarquable, ces formations écotones sont caractérisées par une anthropisation sans cesse croissante. Cependant, très peu d'études se sont focalisées sur les impacts de diverses activités anthropiques sur la structure de la végétation des mangroves.

Dans le cadre de ce travail, nous avons de prime abord (a) évalué les utilisations (commerciales et de subsistances) des produits de mangroves dans la région du Littoral (estuaire du Cameroun). Ensuite, nous avons (b) confronté les usages (de subsistance) des produits de mangroves dans la région du Sud (proche de l'embouchure du fleuve Nyong et du village Mpalla (Kribi)) avec ceux de la région du Littoral. En le faisant, nous avons comparé la perception des résidents locaux sur les changements environnementaux qui se sont produits dans les deux forêts de mangroves régionales. Aussi, nous avons (c) étudié la dynamique structurale de la végétation des mangroves avoisinant la ville de Douala (Cameroun). Toujours aux environs de cette ville, nous avons (d) reconstruit la structure originelle des forêts de palétuviers fortement anthropisées. En outre, nous avons (e) cartographié la structure des mangroves non périurbaines situées dans l'estuaire du Cameroun. Dans cet estuaire, nous avons enfin (f) analysé la structure spatiale du palétuvier noir (*Avicennia germinans* (L.) Stearn).

Nos résultats mettent en exergue une utilisation excessive des produits de mangroves dans l'estuaire du Cameroun. Nous montrons que la fréquence de coupe des palétuviers est relativement faible à Kribi (Mpalla) et à l'embouchure du fleuve Nyong. Les populations locales habitant ces deux localités perçoivent les mangroves comme des écosystèmes peu dégradés. Par contre, celles installées dans l'estuaire du Cameroun les qualifient de milieux fortement anthropisés. En associant les déclarations des locaux à nos observations de terrain, nous avons remarqué que c'est un complexe mixte de causes (création de corridors, pratiques agricoles, extraction de sable et de graviers, coupes excessives et urbanisation anarchique) qui était à l'origine de la forte dégradation des écosystèmes (végétation et sédiments) de mangroves périurbaines camerounaises. L'analyse diachronique (1974, 2001, 2009) du couvert végétal des ces forêts intertidales a révélé qu'en 35 ans, 53,16% des mangroves avoisinant la ville de Douala avaient été perdus. Nous avons également démontré que dans ces zones périurbaines, les coupes de bois s'effectuaient quotidiennement sur les mangroves structurellement plus complexes (sites à densité élevée adjacents aux habitations) (Mboussa Essengue) et, dans une moindre mesure, sur les forêts de palétuviers structurellement plus développées (sites à faible densité distants des zones d'habitations). D'autre part, l'analyse

cartographique des mangroves non périurbaines (distants de Douala) a révélé que la structure de ces formations végétales intertidales était relativement peu anthropisée. Dans l'estuaire du Cameroun, nous montrons également que la structure spatiale d'*Avicennia germinans* (seconde espèce abondante et moins exploitée par les riverains) était aléatoire sur une moitié des parcelles échantillonnées et agregée à certaines distances pour l'autre moitié. En corollaire, cette espèce pourrait jouer un rôle non négligeable dans le processus de recouvrement des trouées artificielles situées dans les zones non périurbaines.

L'approche multidisciplinaire employée dans cette étude nous a permis de mieux appréhender les impacts directs et indirects des activités anthropiques sur la structure de la végétation des mangroves camerounaises. Ces résultats constituent une base de données fondamentale très utile pour le suivi multi-temporel de ces écosystèmes littoraux perpétuellement anthropisés. L'application d'une telle approche dans d'autres mangroves soumises à de fortes pressions anthropiques s'avère importante.

ABSTRACT

Mangroves are intertidal ecosystems found along the tropical and subtropical coastlines. Though globally recognised as ecosystems of ecological, biological and economical remarkable importance, these ecotone formations are characterised by a continuously increasing anthropization. However, very little studies have been focused on the impact of various anthropogenic activities on the mangrove vegetation structure.

We have firstly (a) assessed the commercial and subsistence utilization of mangrove wood products in the Littoral region (Cameroon estuary). Then, we have confronted the subsistence usages of mangrove wood products in the Southern region (close to the mouth of the Nyong River and Mpalla village (Kribi)) in comparison with the Littoral region. By doing, we have compared the local residents' perceptions on environmental changes that occurred within the two regional mangrove forests. Also, we have (c) studied the structural dynamic of mangrove vegetation neighbouring the Douala city (Cameroon). Always in the vicinity of this town, we have (d) reconstructed the original structure of largely disturbed mangrove forests. Moreover, we have (e) map the mangrove structure in a non peri-urban setting located within the Cameroon estuary. Here, we have finally (f) analysed the spatial distribution of a black mangrove namely *Avicennia germinans* (L.) Stearn.

Our results underlined an excessive utilization of mangrove wood products in the Cameroon estuary. We have showed that the frequency of mangrove harvesting was relatively fewer in Kribi (Mpalla) and the mouth of the Nyong River. The local people inhabiting these two localities perceived mangroves as less degraded areas. In contrast, those established within the Cameroon estuary stated that mangroves were largely disturbed. When combining the local people statements with our field observations, we recorded that it a complex mix of causes (*e.i.*, clear-felled corridors, agriculture, sand and gravel extraction, over-harvesting and anarchic urbanization) that have led to the largely degradation (vegetation and sediment) of the peri-urban mangroves in Cameroon. A diachronic analysis (1974, 2003, 2009) of their coverage revealed that over the 35-year period, mangrove had decreases in cover of 53.16% around Douala. We have also showed that in the peri-urban settings, wood harvesting was commonly applied on the structurally more complex (highly dense stands neighbouring the habitations) mangrove forests (Mboussa Essengue) and, in a lesser extent, on the structurally more developed mangrove stands (fewer dense stands faraway from Douala). On the other hand, the mapping analysis of the non peri-urban mangroves (distant from Douala) has revealed that the structure of these intertidal forests was relatively less impacted. In the Cameroon estuary, we also showed that *A. germinans* trees were randomly distributed on almost one-half of the sampling plots and clumped at some scales on the remaining plots.

Accordingly, this species might play a significant role in the recovery process of artificial gaps found in the non peri-urban areas.

The multi-disciplinary approach employed in this study has allowed a better understanding of the direct and indirect impacts of anthropogenic activities on the mangrove vegetation structure in Cameroon. These results constitute a fundamental data base quite useful for the multi-temporal monitoring of these littoral ecosystems perpetually disturbed. The application of similar approach in other mangroves facing high anthropogenic pressures appears important.

Cette dissertation est structurée en 9 chapitres. Elle s'introduit au **Chapitre 1** par la présentation globale des écosystèmes de mangroves et se poursuit par le détail des méthodes utilisées sur le terrain pour mesurer les paramètres structuraux de la végétation des mangroves. Ensuite, elle présente le milieu d'étude, l'état des lieux de la recherche dans les mangroves au Cameroun, la problématique, les objectifs et se termine par les questions de recherches. Le **Chapitre 2** traite les aspects relatifs aux diverses utilisations des palétuviers tout en mettant un accent sur la place qu'ils occupent dans le vécu quotidien des populations riveraines. Dans le **Chapitre 3**, les facteurs perçus par les résidents locaux comme perturbateurs de la structure des mangroves sont présentés. Sur la base de photographies aériennes d'une zone de mangroves périurbaines, les facteurs reportés par les riverains sont analysés du point de vue qualitatif et quantitatif (**Chapitre 4**). Par la suite, une approche originale visant à modéliser *a posteriori* les structures forestières perturbées, et utilisant notamment l'*indice de complexité*, puis proposant divers scénarios de gestion est appliquée (**Chapitre 5**). Afin de vérifier si les perturbations anthropiques sont restreintes aux zones avoisinant les centres urbains, une cartographie de la structure des mangroves non périurbaines est effectuée dans le **Chapitre 6**. Le **Chapitre** 7, pour sa part, analyse la répartition spatiale d'*Avicennia germinans*, la seconde espèce dominante (après *Rhizophora* spp.) et peu exploitée par les communautés locales. Dans le **Chapitre 8**, une discussion générale des résultats découlant des différentes questions de recherches est présentée. Elle est suivie du **Chapitre 9** qui synthétise sous forme de conclusion générale les résultats des différents sujets traités, émet des recommandations et ouvre la voie aux perspectives.

PLANCHE 1. À la découverte de la structure d'une forêt capable de se développer sur un milieu quotidiennement inondé. Les arbres bordant l'un des chenaux du fleuve Wouri (Douala, Cameroun) sont des *Rhizophora racemosa* Meyer.

PLATE 1. At the discovery of the structure of a forest that is able to develop on a daily unundated area. The trees bordering one of the channels of the Wouri River (Douala, Cameroon) are those of *Rhizophora racemosa* Meyer.

CHAPITRE 1

INTRODUCTION GÉNÉRALE

1.1 BREF RAPPEL HISTORIQUE

L'étude descriptive de la mangrove est ancienne. A ce titre, Theophrastes (370–285 av. J.C.) cité par Dahdouh-Guebas & Koedam (2008) mentionne dans les archives historiques que "du côté Est de l'île du Tylos (située dans le Golfe Arabique), il existait un certain nombre d'arbres (mangroves) qui pendant le retrait de la marée formaient une barrière protégeant la zone côtière". Macnae (1968) et Chapman (1976) rapportent pour leur part qu'un manuscrit décrivant le genre *Rhizophora* et ses propagules avait déjà été écrit en 1230 par Abou'l Abass. Une compilation bibliographique effectuée par Rollet (1981) montre qu'avant 1600, il existait 14 références. Cet auteur mentionne également qu'entre 1600 et 1975, l'on dénombrait 3197 références. C'est en fait au début du XX^{e} siècle que les scientifiques commencent à s'intéresser vivement aux forêts de palétuviers. Cela se traduit par un grand nombre de références qui entre 1900 et 1997 se situe autour de 7500 (Cormier-Salem 1994). A la fin de ce siècle, Vannucci (1997) revient sur les liens historiques préexistants entre les mangroves, la culture et les civilisations humaines. Cet auteur détaille clairement les diverses utilisations anciennes des forêts de palétuviers.

Toujours dans la même période (à la fin du XX^{e} siècle), plusieurs théories compétitives ont tenté d'apporter les arguments soutenant une origine unique des mangroves. Srivastava & Binda (1991) défendent la thèse selon laquelle les mangroves se sont développées à partir des plantes terrestres plutôt que marines. Ils justifient leur argumentation en se basant sur la découverte en milieux estuariens, de pollens fossiles de mangroves en dessous d'assemblages de foraminifères marins. D'autre part, la grande diversité spécifique des mangroves Indopacifique Ouest comparée à l'Atlantique Ouest (Spalding *et al.*, 1997) a aussi suscité deux hypothèses. La première soutient que les mangroves se sont dispersées à partir d'un centre d'origine commun qu'est l'Indopacifique Ouest. La seconde hypothèse, celle de la vicariance, relate que toutes les mangroves ont une origine unique qui était située à proximité de l'Océan Théthys. La dérive des continents aurait donc conduit à la séparation de cette flore aujourd'hui observable sur les façades océaniques. Ellison *et al.* (1999) analysent en profondeur ces deux hypothèses et optent plus pour l'hypothèse de vicariance. Les études biochimiques et génétiques ont aussi tenté d'apporter leur contribution afin de clarifier cette origine controversée des mangroves. En démontrant qu'il existe une différenciation génétique significative entre les mangroves de l'Afrique de l'Ouest (cas du Gabon) et celles de l'Amérique du Sud (cas de la Guyane Française), Dodd *et al.* (1998) parviennent à conclure qu'il est peu vraisemblable que les mangroves atlantiques aient été dispersées à partir du Théthys, via le pacifique. Ce débat scientifique est encore d'actualité et seule une intensification des recherches pourrait permettre de valider l'une des hypothèses susmentionnées.

1.2 DÉFINITION ET TYPOLOGIE

Les mangroves sont mondialement reconnues comme l'un des écosystèmes les plus remarquables à cause de leur capacité à se développer le long des littoraux tropicaux et subtropicaux (Baba *et al.*, 2004; Spalding *et al.*, 2010). Ces formations végétales à faible biodiversité sont composées d'arbres et d'arbustes halotolérants capables de s'établir sur des vasières anoxiques et pauvres en éléments nutritifs (Villiers 1973; Dahdouh-Guebas 2002).

Les termes 'mangroves vraies' et 'plantes associées aux mangroves' ont été utilisés pour la première fois par Tansley & Fritsch (1905). Par la suite, cette typologie est abordée par Arulchelvam (1968) et Lugo & Snedaker (1974). Elle est reprise par Saenger *et al.* (1983) et Ricklefs & Latham (1993) qui utilisent les expressions 'mangroves exclusives' et 'mangroves non exclusives'. Quant à Tomlinson (1986), il sépare et subdivise ces deux entités en 'composantes majeures des mangroves' qui sont des 'mangroves vraies, exclusives ou strictes', et en 'éléments mineures des mangroves' qui représentent les plantes associées aux mangroves vraies. Cet auteur qualifie une plante de composante majeure des mangroves lorsqu'elle se développe préférentiellement dans les zones de balancement des marées et jamais en milieu terrestre. Elle doit donc pouvoir s'adapter aux variations de salinité et se distinguer taxonomiquement des plantes qui lui sont apparentées en milieu terrestre. Il ajoute que cette plante doit être capable de croître sur les vasières inondables par le biais des racines aériennes, la viviparité de l'embryon ou des échanges gazeux. Bien que cette classification ait été acceptée par plusieurs auteurs (Duke 2006; Kathiresan & Bingham 2001; Lacerda *et al.*, 2002; Saenger 2002; Wang *et al.*, 2003), elle reste selon Duke (1992) peu claire.

En outre, Dahdouh-Guebas *et al.* (2005a) précisent qu'une distinction additionnelle devrait être faite d'une part entre les mangroves euryhalines (*Avicennia marina* Forsk. Vierh.), résistantes à une perturbation (*Excoecaria agallocha* L.) ou modérément adaptées à l'eau douce (*Sonneratia caseolaris* L.) et celles qui sont écologiquement plus vulnérables vis-à-vis des activités de coupes du bois et, d'autre part, entre les deux catégories susmentionnées et les espèces considérées comme les plus caractéristiques des mangroves matures naturelles (Rhizophoracées).

Cette distinction étant nécessaire pour détecter la dégradation écologique cryptique (phénomène selon lequel une espèce associée aux vraies mangroves ou un élément mineur de ces écosystèmes littoraux commence doucement à dominer la forêt de mangroves vraies (dégradation qualitative) sans perte de la couverture spatiale d'une forêt) (Dahdouh-Guebas *et* *al.*, 2005b).

D'autre part, Wang *et al.* (2010) apportent leur contribution à cette discussion en démontrant que les vraies espèces de mangroves sont des halophytes vraies alors que les espèces associées aux mangroves sont des glycophytes avec un certain degré de tolérance au sel.

1.3 ADAPTATIONS MORPHOLOGIQUES

Les plantes de mangroves possèdent un certain nombre de traits caractéristiques qui facilitent leur adaptation à l'environnement rude que présente l'interface terre-océan. Ceux-ci varient en fonction du genre considéré et de la nature physico-chimique de l'habitat (Duke 1992).

Le type de système racinaire est souvent perçu comme l'une des plus remarquables adaptations. A titre d'exemple, on peut mentionner les racines échasses ou aériennes de *Rhizophora*, les pneumatophores d'*Avicennia*, *Sonneratia* et *Lumnitzera*, les racines genouillées de *Bruguiera* et *Ceriops* et les contreforts de *Xylocarpus* et *Heritiera*. Les racines sont très souvent peu profondes et par conséquent présentent une extension latérale accentuée. Cette extension leur permet de maintenir l'arbre sur un substrat généralement instable, anaérobique et enrichi en sulfates marins (Tomlinson 1986; Kathiresan & Bingham 2001). En addition à ce rôle de support, les racines interviennent également dans les processus physiologiques.

1.4 ADAPTATIONS PHYSIOLOGIQUES

La fonction physiologique des racines de mangroves s'illustre par leur capacité à assurer les échanges gazeux respiratoires entre la plante et le milieu extérieur. Les lenticelles (sorte de petits boutons ovoïdes) présentes sur leur surface externe s'ouvrent généralement en période de marée basse et permettent une diffusion de l'air. Elles se referment aussitôt que la marée est montante. À ce moment, les tissus racinaires submergés par l'eau saumâtre doivent développer les facultés de survie.

Les systèmes racinaires des genres *Rhizophora*, *Bruguiera* et *Ceriops* sont équipés d'ultrafiltres qui excluent l'excès de sel pendant qu'ils absorbent l'eau du substrat (Tomlinson 1986). Par contre, *Avicennia* préfère incorporer l'eau salée et excréter les cristaux de sel grâce aux glandes salines spécialisées que l'on trouve dans les feuilles. Une autre façon de réguler le sel, tout à fait différente des précédentes, est développée par *Lumnitzera* et *Excoecaria*. Ces deux genres accumulent le sel à l'intérieur des vacuoles foliaires, ce qui conduit à une succulence des feuilles. D'autre part, la quantité de sel contenue dans la sève brute peut être réduite suite à un transfert vers les feuilles mortes ou par le stockage dans l'écorce ou le bois (Tomlinson 1986; Kathiresan & Bingham 2001).

1.5 DISTRIBUTION GÉOGRAPHIQUE

L'évolution et la répartition de la végétation des mangroves à l'interface terre-océan sont fortement influencées par les paramètres climatiques. En effet, ces écosystèmes intertidaux présentent dans leur globalité une limite latitudinale (Fig. 1.1) qui se situe approximativement entre 30°N et 30°S (limite marquée par les tropiques du Cancer et du Capricorne) (Spalding *et al.*, 2010; Giri *et al.*, 2011). Selon Chapman (1976), les mangroves ne peuvent se développer de façon normale qu'uniquement dans les régions où la température moyenne de l'air du mois le plus froid est supérieure à 20°C et l'amplitude thermique inférieure ou égale à 10°C.

Tomlinson (1986), à la suite de Chapman (1976) distingue géographiquement deux groupes. Les formations de l'Hémisphère Est, désignées mangroves indo-pacifiques, incluent les mangroves de l'Afrique de l'Est, de l'Inde, de l'Asie du Sud-Est, de l'Australie et de l'Ouest du Pacifique. Les mangroves atlantiques représentant le second groupe se trouvent à l'Hémisphère Ouest. Elles sont composées des formations de l'Afrique de l'Ouest et du Centre, de l'Amérique du sud, de la Floride, des Caraïbes, de l'Amérique centrale, du pacifique nord et de l'atlantique sud de l'Amérique.

Dans le continent américain, les forêts de palétuviers possédant une superficie supérieure à 1000 km^2 sont celles du Brésil (12999,47 km^2), du Mexique (7700,57 km^2), de Cuba (4944,05 km^2), de Colombie (4079,26 km^2), du Venezuela (3569,11 km^2), des Etats Unies d'Amériques (3029,55 km^2), du Panama (1744,44 km^2) et d'Equateur (1582,61 km^2) (Spalding *et al.*, 2010). Une représentation exhaustive des mangroves à faible couvert végétal de ce continent est illustrée par les mêmes auteurs.

L'Océan Indien et l'Océan Pacifique qui délimitent le continent asiatique ont au niveau de leurs côtes des mangroves à haute diversité spécifique dont les plus marquées sont celles d'Indonésie (31893,59 km^2), de Malaisie (7097,30 km^2), de Myanmar (5029,11 km^2), du Bangladesh (4951,36 km^2), d'Inde (4325,92 km^2), de Nouvelle-Guinée (4264,82 km^2), des Philippines (2564,82 km^2), de Thaïlande (2483,62 km^2) et du Vietnam (1056,08 km^2) (Spalding *et al.*, 2010). Les mangroves bordant les côtes australiennes couvrent une superficie d'environ 11500 km^2 (Duke 2006).

Sur le continent africain, les mangroves sont principalement réparties le long de la côte occidentale en partant de la Mauritanie jusqu'en République Démocratique du Congo (UNEP

2007). En Afrique de l'Ouest et Centrale, les grandes superficies de mangroves se rencontrent au Nigéria (7355,57 km^2), en Guinée Bissau (2982,21 km^2), en Guinée (2033,45 km^2), au Cameroun (1961,84 km^2), au Gabon (1597,52 km^2), au Sénégal (1279 km^2) et en Sierra Leone (1048,89 km^2) (UNEP 2007; FAO 2007; Spalding *et al*., 2010). Sur les côtes orientales de l'Afrique, les mangroves du Mozambique (2909 km^2), de Madagascar (2991,12 km^2) et de Tanzanie (1286,83 km^2) ont une large couverture végétale comparées à celles du Kenya (609,51 km^2) (Taylor *et al*., 2003).

FIG. 1.1 Carte de distribution globale des forêts de mangroves (Giri *et al.*, 2011)

1.6 DIVERSITÉ SPÉCIFIQUE

1.6.1 *Flore des mangroves*

Bien que les forêts de mangroves présentent une large distribution géographique, les espèces végétales qui composent ces écosystèmes côtiers ne sont pas toujours régulièrement réparties sur les différentes façades océaniques (Fig. 1. 2). Il est tout à fait évident que les principales barrières limitant la dispersion des propagules entre différentes côtes continentales restent les éléments intermédiaires que sont les océans. Par ailleurs, il convient de noter qu'en dépit de l'existence de ces facteurs restrictifs aux flux de gènes, des études récentes suggèrent par exemple que le lien génétique entre des peuplements d'*Avicennia germinans* (L.) Stearn rencontrés en Amérique du Sud et en Afrique de l'Ouest est plus important qu'il ne l'est avec leur voisin d'Amérique du Nord (Triest 2008).

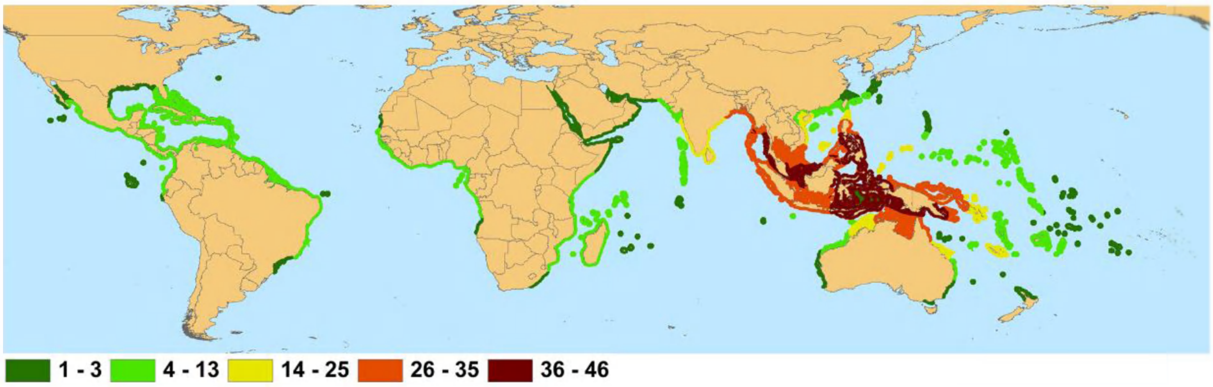

FIG. 1.2 Richesse spécifique globale des mangroves (Polidoro *et al.*, 2010). Les espèces introduites telles que *Rhizophora stylosa* Griff. (France Polynésienne), *Bruguiera sexangula* (Lour) Poir, *Conocarpus erectus* L., et *Rhizophora mangle* L. (Hawaii), *Sonneratia apelata* Buch.-Ham. (Chine) et *Nypa fruticans* (Thurnb. Wurmb.) (Cameroun et Nigéria) ne sont pas prises en compte lors de l'élaboration de cette carte. Chaque chiffre représente le nombre d'espèces non introduites rencontrées le long des côtes orientales et occidentales.

Le nombre d'espèces végétales qualifiées de mangroves vraies varie en fonction des auteurs, selon que ces derniers intègrent ou non les espèces hybrides ou controversées (celles-ci sont à la fois considérées comme plantes exclusives ou associées aux forêts de mangroves). Tomlinson (1986) dénombre 54 espèces de mangroves vraies et les classe dans 20 genres et 16 familles. Duke (1992) pour sa part identifie 69 espèces, 26 genres et 20 familles. Sur base des descriptions faites par les auteurs précédent et la classification APGIII (APG 2009; Chase & Reveal 2009), une base de données rationnelle ("*Mangrove Reference Database and Herbarium*") identifiant 73 vraies espèces de mangroves a été établie et est accessible *via* le lien http://www.vliz.be/vmdcdata/mangroves/ (Massó i Alemán *et al.*, 2010).

1.6.2 *Faune des mangroves*

La faune aérienne des mangroves est constituée d'oiseaux, d'insectes, de mammifères et de reptiles. Celle aquatique est quant à elle composée de poissons, de crustacées, de mollusques, de tuniciers et d'éponges. Un inventaire exhaustif de la faune des mangroves n'a pas encore été réalisé. Néanmoins, une revue des espèces animales associées aux forêts de mangroves est documentée par Nagelkerken *et al.* (2008). Ces auteurs mentionnent un certain nombre de pays possédant le record d'espèces faunistiques. Il s'agit de: l'Australie (184 espèces d'oiseaux et 39 espèces de mollusques), les Caraïbes (147 espèces d'éponges), le Sénégal (130 espèces de poissons), le Singapour (102 espèces d'insectes herbivores), l'Inde (32 espèces de copépodes) et la Colombie (29 espèces de bivalves).

1.7 IMPORTANCE DES MANGROVES

1.7.1 *Importance écologique*

Les forêts de mangroves jouent un rôle de barrière contre certaines catastrophes naturelles. C'est ainsi qu'elles protègent les populations environnantes des dommages que peuvent causer les cyclones, ouragans et tsunamis (Dahdouh-Guebas 2006; Alongi 2008). Hong et San (1993) rapportent également que les mangroves en limitant l'érosion côtière, participent à l'avancée de la terre vers l'océan tout en constituant une zone tampon dans les régions sujettes aux tempêtes et aux cyclones. Barbier (2007) pour sa part souligne que les mangroves jouent également un rôle dans le maintien de la biodiversité et le contrôle de la pollution. A travers la rétention de nombreux débris grossiers ainsi que des sédiments, les racines enchevêtrées des palétuviers participent à la filtration de l'eau estuarienne (Lin & Dushoff 2004).

Dans les tropiques, les mangroves sont classées parmi les forêts les plus riches en carbone (Donato *et al.*, 2011). Comme tout écosystème forestier, les mangroves fixent le CO_2 atmosphérique et participent ainsi à la lutte contre le réchauffement climatique dont est victime notre planète (Alongi 2011). Bouillon *et al.* (2004) signalent que les mangroves interviennent de manière significative dans la stabilité du climat car les estimations récentes montrent que 11% environ de la masse totale de carbone organique à l'interface terre-océan sont fixés par les mangroves. Ces écosystèmes côtiers atténuent également les effets négatifs issus de l'augmentation du niveau de la mer (Ellison 2003; Di Nitto *et al.*, 2008). Il a été démontré récemment qu'une population de palétuviers à densité élevée favorise l'accrétion des sédiments et en corollaire l'élévation de la surface côtière (Kumara *et al.*, 2010).

1.7.2 *Importance biologique*

Le long des côtes tropicales, les mangroves constituent un habitat pour divers vertébrés (singes, tigres, crocodiles, serpents, oiseaux) et invertébrés (crabes, gastéropodes, insectes,..) (Kathiresan &. Bingham 2001). Ce sont également des zones préférentielles de pêche pour les communautés côtières. Elles fonctionnent aussi comme des zones de reproduction, de ponte et d'éclosion des œufs, de croissance de jeunes poissons et des crustacés et constituent donc pour la faune aquatique un habitat important permettant d'assurer la pérennité des espèces concernées (Nagelkerken *et al.*, 2008). Ainsi, les estimations récentes montrent qu'environ 80% de poissons sont directement ou indirectement dépendant des mangroves (Sullivan 2005; Ellison 2008).

1.7.3 *Importance économique*

Les plantes de mangroves sont collectées de manière courante non seulement pour la construction des habitations mais aussi pour le bois de chauffe et le charbon, la médicine, la fabrication d'insecticide et de certaines fournitures (Dahdouh-Guebas *et al.*, 2000a; Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009). Elles sont par ailleurs utilisées pour l'agriculture (Hossain *et al.*, 2009), l'implantation de l'aquaculture[†] (Guimarães *et al.*, 2010) et l'extraction du sable (bien que ces activités anthropiques soient aussi considérées comme facteurs destructeurs des mangroves).

Le coût estimatif des services offerts par les écosystèmes de mangroves est évalué à environ 1,5 milliards US$ (Costanza *et al.*, 1997). Ces forêts intertidales peuvent servir de milieu récréatif lorsqu'on y développe les activités d'écotourismes (Barbier *et al.*, 2011). Le revenu principal de la majorité des populations résidant à l'intérieur ou au voisinage des zones de mangroves provient de ces écosystèmes côtiers (Krauss *et al.*, 2008; Walters *et al.*, 2008). Ces zones de frayères sont très indiquées pour la collecte quotidienne des ressources halieutiques (poissons, crabes, crevettes, bivalves, huitres…) qui sont généralement commercialisées par les populations des zones côtières. A titre d'exemple, la zone côtière camerounaise produit annuellement environ 10000 tonnes de crevettes d'estuaires (*Palaemon hastatus* Auriv.) (MINEF 1996). Aussi, depuis l'Eocène jusqu'à présent, d'importants processus sédimentologiques se sont déroulés au large des bassins du Rio del Rey et de Douala/Kribi Campo. Ces derniers ont conduit à la formation de réservoirs pétrolifères sur lesquels se développent les forêts de mangroves camerounaises (Doust & Omatsola 1990;

[†] Bien que cette activité anthropique constitue une source de revenue pour les communautés côtières, elle reste tout de même l'une des principales causes de destruction des forêts de mangroves.

Mbendi 2005).

1.8 FACTEURS DE DESTRUCTION

Au vue de leur grande valeur écologique, biologique, économique, sociale, culturelle, scientifique et touristique, les écosystèmes de mangroves d'après les conventions internationales sur les milieux humides sont considérés comme zones à protéger (RAMSAR 1994). Toute action anthropique dans ces milieux côtiers devrait donc être régulée. Cependant, les données globales rapportent que moins de 20% d'habitats des mangroves sont situés dans les zones protégées (Chape *et al.*, 2005). En Afrique, 14% seulement des mangroves existantes se retrouvent à l'intérieur d'une zone protégée dont l'entièreté n'est pas gérée de façon active (UNEP 2007). La conséquence immédiate est mise en évidence dans plusieurs études qui démontrent qu'entre 20-35% de la superficie originale des mangroves a été perdue depuis 1980 (Valiela *et al.*, 2001; FAO 2007). Pendant la même période, les taux de perte en Afrique et au Cameroun sont respectivement estimés à environ 13,8% et 8,08% (FAO 2007). Comparé à l'Océanie (9,58%) ou à l'Afrique, les pertes s'avèrent plus importantes en Amérique (18,01%) ou Asie (24,59%) (FAO 2007).

Les perspectives d'un monde sans mangroves pourraient être une réalité dans les cent prochaines années (Duke *et al.*, 2007) car les pressions aussi bien anthropiques que naturelles sont en pleine croissance le long des côtes tropicales (Walters *et al.*, 2008; Mukherjee *et al.*, 2010). Polidoro *et al.* (2010) soulignent par exemple que 16% de l'ensemble des espèces exclusives aux mangroves présentent un risque élevé d'extinction. La destruction de ces forêts entraîne non seulement la modification de leur structure mais aussi la perte des fonctions écologiques, biologiques et économiques (Ewel *et al.*, 1998; Mumby *et al.*, 2004; Nagelkerken *et al.*, 2008; Walters *et al.*, 2008).

1.8.1 *Facteurs naturels*

Les impacts négatifs des catastrophes naturelles (cyclones, ouragans, tsunamis) sur les écosystèmes tropicaux ont été globalement détaillés ces dernières années (Dahdouh-Guebas & Koedam 2006a; Kerr & Baird 2007; Koedam & Dahdouh-Guebas 2008; Das & Vincent 2009; Feagin *et al.*, 2010). En plus de celles-ci, les mangroves doivent également faire face à l'augmentation relative du niveau de la mer qui est un résultat des changements climatiques (Gilman *et al.*, 2006, 2008; Di Nitto *et al.*, 2008; Ross *et al.*, 2008). Dans les zones à dominance marine, les dépôts successifs de sable sur les berges océaniques recouvrent généralement les lenticelles des pneumatophores d'*Avicennia* entrainant ainsi la mort physiologique des mangroves (Satyanarayana *et al.*, 2011). Aussi, lorsque ces berges sont soumises aux vagues violentes, cela peut provoquer la chute des palétuviers. Toutefois, celles-ci perturbent moins ces écosystèmes côtiers comparées aux coupes d'origines humaines.

1.8.2 *Facteurs anthropiques*

Les pertes énormes du couvert végétal des mangroves sont en grande partie dues aux diverses pressions anthropiques sans cesse croissantes qui y sont exercées (Dahdouh-Guebas 2002; Duke *et al.*, 2007; Spalding *et al.*, 2010). Par ailleurs, la destruction des mangroves apparaît ainsi comme le résultat de leur utilisation pour l'aquaculture, l'agriculture, la riziculture, l'urbanisation anarchique, la coupe excessive du bois, et les activités pétrolières (Farnsworth & Ellison 1997; Duke *et al.*, 1997; Lamparelli *et al.*, 1997; Cormier-Salem 1999; Dahdouh-Guebas *et al.*, 2000a; Hernández-Cornejo *et al.*, 2005; Walters *et al.*, 2008; Din *et al.*, 2008; FAO 2007; Nfotabong Atheull *et al.*, 2009).

En outre sur les côtes camerounaises, les activités minières, l'exploitation pétrolière, l'extension du domaine portuaire vers la crique Docteur à Douala, l'agrandissement de la zone industrielle de Bonabéri, les nouveaux forages dans l'embouchure du fleuve Sanaga et ceux projetés à l'embouchure du fleuve Nyong, la construction du pipeline Tchad-Cameroun, l'extraction du sable, la création des villages et des campements de pêche sont d'autres causes évidentes d'anthropisation de la structure des mangroves (MINEF 1996).

La côte camerounaise a déjà connu des déversements accidentels de pétrole. Akum (2005) souligne que cela s'est déroulé à la Société National de Raffinerie (SONARA) quand celle-ci pompait du pétrole d'un camion-citerne vers un réservoir de stockage. Afin de limiter la pollution industrielle des côtes camerounaises, certains auteurs proposent un certain nombre de recommandations dont les plus marquantes incluent un monitoring adéquat des polluants, la mise en place de forums de discussions impliquant toutes les composantes institutionnelles et l'ouverture d'une voie de recherche en créant des partenariats avec les universités locales (Alemagi *et al.*, 2006).

1.9 STRUCTURE DE LA MANGROVE

1.9.1 *Définition*

La structure de la végétation des mangroves de prime abord fait référence au patron de zonation qui correspond à la distribution séquentielle des groupements végétaux des rivages vers le continent ou vice-versa. Celle-ci peut aussi être non zonée lorsqu'elle est formée d'une mosaïque de groupements végétaux monospécifiques ou d'un assemblage de petites portions dissociées de végétation à formes et superficies variables (Dahdouh-Guebas & Koedam

2002). La structure des forêts de palétuvier représente également la manière dont ses différentes composantes sont arrangées à l'intérieur de chaque séquence spatiale qui peut être proche, peu ou très distante de la rive. Dans certains cas, l'arrangement des individus peut être très irrégulier ou restreint à une zone caractérisée par un gradient d'inondation particulier (zonation partielle). Plusieurs méthodes peuvent être utilisées sur le terrain pour mesurer les paramètres structuraux d'une ou plusieurs séquences de végétation de mangroves.

1.9.2 *Méthodes de mesure sur le terrain*

Les méthodes de quadrat et distance sont le plus souvent utilisées sur le terrain pour mesurer les paramètres structuraux des palétuviers.

1.9.2.1 Méthode de quadrat

Cette méthode consiste à effectuer des parcelles de dimensions bien définies à l'intérieur desquelles l'on caractérise la structure de la végétation. Largement utilisée, elle permet un échantillonnage exhaustif de tous les éléments que contient une parcelle (Kent & Coker 1992; Elzinga *et al.*, 2001). Néanmoins, son exécution n'est pas facile dans les forêts de mangroves à cause de la nature du substrat qui rend les déplacements difficiles. Le choix de la dimension d'une parcelle est fonction du type de végétation étudié (Cintrón & Schaeffer Novelli 1984). A ce titre, les petites parcelles (1 m × 1 m ou 5 m × 5 m) sont le plus souvent utilisées lorsque les mesures doivent s'effectuer sur les populations juvéniles à densités élevées. Quand il s'agit d'arbres jeunes et adultes (diamètre > 2,5 cm), la taille des parcelles varie entre 100 m^2 (10 m × 10 m) et 400 m^2 (20 m × 20 m).

1.9.2.2 Méthodes de distance

Parmi les méthodes de distance, on distingue la Méthode de Point-Centré au Quart (PCQM) (voir Fig. 1.3), la méthode T-carré (*T-square*), du voisin le plus proche (*Nearest Neighbor*), d'échantillonnage de paires aléatoires (*Random pairs sampling*). Notons tout de même que les trois dernières méthodes de distances susmentionnées n'ont pas été utilisées dans le cadre de ce travail.

L'utilisation de la PCQM en écologie débute à la moitié du siècle passé (Cottam & Curtis 1956). C'est une méthode qui permet une estimation rapide des paramètres de structure d'une forêt sur de grandes étendues. Elle est très convenable pour l'étude structurale des milieux à substrats vaseux et instables tels que les mangroves (Cintrón & Schaeffer Novelli 1984). Elle consiste à positionner des points d'échantillonnage le long d'un transect orienté à l'aide d'une boussole ou d'un '*Global positioning System*' (GPS). Ces points doivent être distants de manière à éviter des mesures répétitives sur des individus. Chaque point d'échantillonnage est considéré comme le centre de quatre quadrants à l'intérieur desquels les arbres les plus proches du centre sont repérés et échantillonnés (Fig. 1. 3). Les limites et les adaptations (PCQM+) de cette méthode sont détaillées par Dahdouh-Guebas & Koedam (2006b).

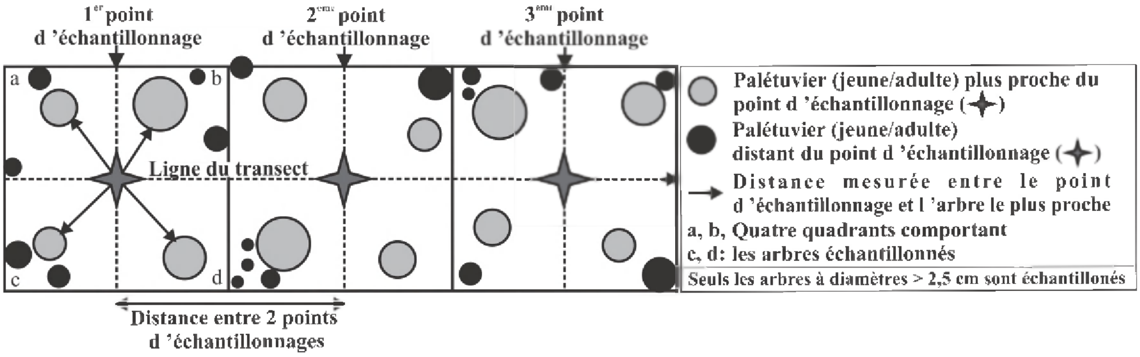

FIG. 1.3 Schéma simplifiée de la méthode de Point-Centré au Quart (PCQM).

1.9.3 *Caractérisation de la structure des mangroves par télédétection*

La télédétection, ou détection à distance, est une technique qui rend possible la reconnaissance et l'analyse des objets ou des phénomènes terrestres à partir d'informations de nature énergétique (rayonnement électromagnétique) enregistrées par un capteur sous diverses formes (négatif ou numérique) à bord des plates-formes aéroportées (vol en ballons, avions), spatiales (satellites, navette spatiale), terrestres ou maritimes (Bonn 1994; Wolff 2005). On distingue une télédétection dite passive (enregistrement du rayonnement solaire réfléchi et émis par les surfaces terrestres) et une autre qualifiée d'active (enregistrement d'un rayonnement artificiel provenant d'un émetteur (RADAR) et réfléchi par les surfaces terrestres) (Barrett & Curtis 1982). Dans les domaines spectraux (*cf.* Fig. 1. 4), le visible est réfléchi par les surfaces terrestres. En ce qui concerne la végétation et l'eau, la longueur d'onde la plus utilisée est le proche infrarouge.

Les pellicules photographiques n'enregistrent que les longueurs d'ondes se trouvant dans le visible et l'infrarouge alors que l'enregistrement des capteurs embarqués à bord des satellites s'étend de l'ultraviolet (rare) aux hyperfréquences (Fig. 1. 4). L'énergie électromagnétique enregistrée est donc analysée et l'information est traitée. La combinaison de ces données avec les Systèmes d'Informations Géographiques (SIG) (bases de données à références spatiales) et la modélisation spatiale permet d'améliorer les aptitudes d'évaluation des degrés, patterns et directions de changements à travers le paysage (Turner 1989; Cohen *et al.*, 2002). La capacité de couverture répétitive du capteur offre des données largement utiles pour la détection et le suici des impacts humains sur la structure de la végétation Dahdouh-Guebas 2002). Le principe basé sur l'acquisition d'une variété d'images à l'échelle locale, régionale ou globale facilite l'estimation de la dynamique structurale et des paramètres biophysiques des milieux peu accessibles comme les mangroves.

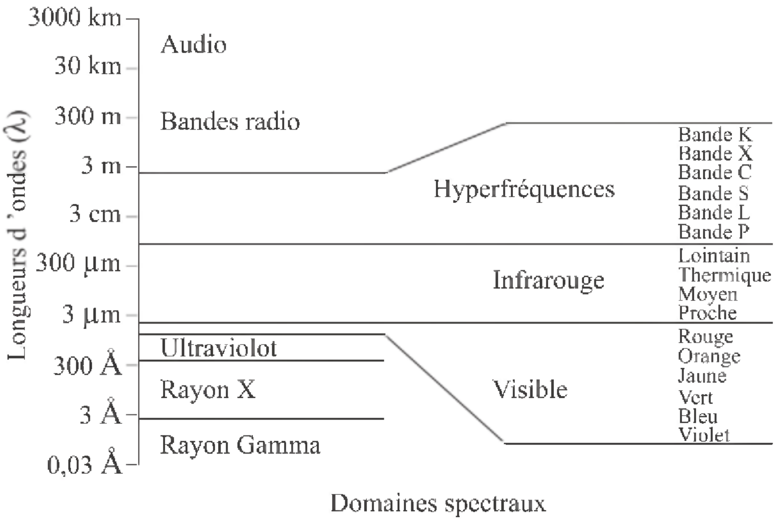

FIG. 1.4 Spectre électromagnétique du rayonnement solaire d'après Bonn (1994).

1.9.3.1 Photographie aérienne

C'est en 1895 que la première pellicule couleur a été mise au point (Bonn 1994). La prise de vue aérienne à partir d'avions militaires commence en 1909. L'exploitation civile des données émanant de ces missions aéroportées n'est effective qu'après plusieurs années.

Parmi les différents types d'émulsion, on distingue des films noirs et blancs panchromatiques (sensibilité à tous les rayonnements du visible) ou proches infrarouges (la sensibilité peut s'étendre jusqu'à l'ultraviolet), couleurs (sensibilité au bleu, vert et rouge) et proches infrarouges fausses couleurs (sensibilité au vert, rouge et proche infrarouge).

La photographie aérienne est le premier outil de détection à distance qui a permis de cartographier la végétation des zones inondables (Seher & Tueller 1973; Shima *et al.*, 1976; Lehmann & Lachavanne 1997; Howland 1980). L'avantage de ce type de données archivables réside dans sa capacité à révéler l'historique d'un paysage donné (Everitt *et al.*, 2010). Lorsqu'une couverture photographique présente une échelle de prise de vue élevée, celle-ci est très convenable pour caractériser localement les paramètres de structure d'une forêt (*cf.* Couteron *et al.*, 2005). Cependant, son utilisation n'est pas appropriée pour effectuer un suivi à l'échelle régionale à cause du coût d'acquisition élevé et le temps nécessaire aux divers traitements numériques. Les données satellitaires présentent des atouts considérables permettant de pallier ce type de contrainte.

1.9.3.2 Images satellites

Chaque satellite (vecteur) d'observation de la Terre possède un capteur spécifique qui enregistre et traite le rayonnement électromagnétique (une description détaillée de ces deux entités est disponible via le lien internet: http://eo.bels.be/News/Default.aspx). A l'issu du traitement, l'émetteur renvoie l'information sous forme d'images sur Terre vers une station de réception. Les images réceptionnées peuvent être différenciées sur la base de leur résolution spectrale (nombre de bandes spectrales et longueurs d'ondes enregistrés), spatiale (taille au sol d'un *pixel* (*picture element*) de l'image ou de la scène entière) et radiométrique (détail avec lequel le signal est enregistré et discrétisé).

Le capteur *Multi-Spectral Scanner* (MSS) embarqué à bord des satellites LANDSAT 1-3 fournit des images peu détaillées du point de vue radiométrique. Celles-ci ont tout de même une résolution spatiale moyenne (79 m) qui reste convenable pour les études rétrospectives à l'échelle régionale. Dans l'optique d'améliorer la qualité de l'enregistrement, les satellites LANDSAT 4-5 ont été équipés du capteur *Thematic Mapper* (TM). La résolution spatiale (30 m) est identique pour toutes les bandes excepté l'infrarouge thermique (120 m). Comparée au MSS, l'information radiométrique est plus détaillée et peut ainsi être exploitée pour une étude sous-régionale. Bien que le lancement de LANDSAT 6 ait échoué, une nouvelle tentative de mise en orbite, cette fois réussie, d'un autre vecteur (LANDSAT 7) portant à son bord le capteur *Enhanced Thematic Mapper* (ETM+) a encore permis d'améliorer la résolution spatiale des bandes enregistrées dans le visible (15 m) et l'infrarouge thermique (60 m).

Afin de concurrencer les satellites américains susmentionnés, les européens lancent en 1986 le Satellite Probatoire d'Observation de la Terre (SPOT). Parmi les cinq satellites qu'ils ont mis en orbite, seuls trois (SPOT 2, 4 et 5) sont encore fonctionnels. SPOT 2 possède deux capteurs Haute Résolution Visibles (HRV1 et 2) qui enregistrent en mode panchromatique (10 m) et multispectral (20 m). SPOT 4 et 5 transportent des capteurs Haute Résolution Visible et Infrarouge (HRVIR).

Le satellite indien (*Indian Remote Sensing* (IRS)), lancé en 1995, porte le capteur *Linear Imaging Self Scanning Sensor* (LISS). Celui-ci n'enregistre pas dans l'infrarouge moyen. Une documentation détaillée des satellites IRS et capteurs LISS-III, LISS-IV et AWiFS (*Advanced Wide Field Sensor*) est accessible via le lien http://eoedu.belspo.be/fr/satellites/irs.htm.

A la suite des vecteurs IRS, le satellite TERRA portant à son bord le capteur ASTER (*Advanced Spaceborne Thermal Emission and reflection Radiometer*) a été lancé en 1999. Celui-ci enregistre dans le visible et le proche infrarouge avec une résolution de 15 m. Toujours en 1999, le satellite CBERS-1 (*China-Brazil Earth Resource Satellite*) a été mis en orbite suite à une coopération entre la CAST (*Chinese Academy Space of Technology*) et l'INPE (*National Institute for Space Research*). Ce vecteur embarque à son bord trois caméras (CCD, WFI (*Wide Field Imager*) et IRMSS (*Infrared Multispectral Scanner*)) qui fournissent une diversité d'images largement utiles dans la planification urbaines et le suivi de la déforestation en Amazonie. CBERS-1 a été remplacé en 2003 par CBERS-2. En 2007, ce dernier a été substitué par CBERS-2B. Dans celui-ci, l'IRMSS a cédé sa place au capteur HRC (*High Resolution Camera*). Un problème d'ordre énergétique est survenu à bord du CBERS-2B et a conduit, en Mai 2010, à la fin des opérations de ce satellite. Le lancement de CBERS-3 est prévu dans la seconde moitié de l'année 2011 (pour en savoir plus sur les opérations de CBERS, visitez le site http://www.inpe.br/ingles/news/news_dest118.php).

Les images produites par l'ensemble des capteurs énumérés ci-dessus (exceptées celles issues de la caméra HRC), bien qu'étant de haute résolution, ne sont pas appropriées pour la cartographie des paramètres de structure (analyse texturale) des forêts comme le sont celles obtenues à partir des satellites COSMOS, IKONOS, QuickBird qui ont une très grande résolution spatiale (*cf.* Tableau 1.1).

Tableau 1.1 Données synthétiques des satellites observant la Terre à très haute résolution.

Vecteur	Début	Capteur	Résolution (m)	Altitude (km)	Inclinaison (°)	Taille de la scène (km)
COSMOS	1987	KVR1000	2-3	190-270	70	40
CBERS-2B	1999	HRC	2,7	778	±32	27
IKONOS	1999	IKONOS XS IKONOS P	4 1	681	98,1	11
QuickBird	2001	QuickBird XS QuickBird P	2,44-2,88 0,61-0,72	450	97,2	16
GeoEye 1	2008	GeoEye XS GeoEye P	1,65 0,41	681	98	15,2

Les vecteurs COSMOS et CBERS-2B collectent les images panchromatiques tandis que les satellites IKONOS, QuickBird et GeoEye-1 enregistrent les données simultanément en mode panchromatique (P) et multispectral (XS). La combinaison des données issues de ces deux modes d'enregistrement permet d'obtenir une image en vraie ou fausse couleur à très haute résolution. Les prises de vues effectuées par QuickBird et GeoEye-1 sont accessibles *via* l'interface Google Earth™.

Les informations supplémentaires concernant les satellites IKONOS, QuickBird et GeoEye 1 sont également disponibles sur http://www.satimagingcorp.com/satellite-sensors/ikonos.html, http://www.satimagingcorp.com/satellite-sensors/quickbird.html et http://www.ssd.itt.com/heritage/geoeye.shtml.

1.10 MILIEU D'ÉTUDE

1.10.1 *Contexte général des mangroves au Cameroun*

Le long des côtes camerounaises, les mangroves couvrent une superficie actuellement estimée à environ 1961,84 km^2 (Spalding *et al.*, 2010). Elles sont distribuées principalement entre deux estuaires (estuaire du Rio del Rey et estuaire du Cameroun) mais sont présentes également sous forme de petits peuplements à superficies variables dans la région du Sud-Cameroun (Campo, Kribi, Londji, embouchures des fleuves Lokoundjé et Nyong) (Fig. 1.5). Ces dernières sont entourées de l'immense forêt dense humide de terre ferme.

Les mangroves au Cameroun sont protégées par la loi n° 96/12 du 05 août 1996 fixant le cadre juridique de la gestion de l'environnement au Cameroun. Elle stipule dans son article 94 que "les écosystèmes de mangroves font l'objet d'une protection particulière qui tient compte de leur importance dans la conservation de la diversité biologique marine et le maintien des équilibres écologiques côtiers". Cependant, l'application de cette loi n'est pas effective et par conséquent expose ces milieux estuariens à une exploitation irrationnelle (Nfotabong Atheull *et al.*, 2009). Rappelons que le 13 janvier 2006, le Cameroun a adhéré à la convention de RAMSAR qui protège les zones humides.

L'évolution naturelle de la végétation des mangroves de l'estuaire du Rio del Rey est surtout influencée par la densité du réseau hydrographique dont la dynamique est très souvent à l'origine non seulement de la chute des arbres au niveau de la façade atlantique (Din 2001) mais aussi de la large dispersion des graines de *Nypa fruticans*. Cette espèce, introduite par Calabar (Nigéria) en 1906 représente dans certaines zones de mangrove mature ou sénescente l'élément dominant de la strate inférieure et moyenne qui à l'issue d'une coupe intense remplacera certainement l'actuelle forêt de palétuviers.

Bien que cette forêt sempervirente, peu dense et aux futaies élevées soit actuellement soumise à de fortes pressions anthropiques, elle connaitra sans doute dans un futur proche diverses perturbations additionnelles résultant des activités d'exploitations pétrolières. Il s'avère donc important d'intensifier ultérieurement les travaux de recherches sur ce terrain jadis conflictuel et qui reste actuellement peu connu de la communauté scientifique. Les résultats émanant de ces études s'additionneront à ceux de Din *et al.* (2001a) pour constituer une véritable base de données permettant d'assurer le suivi de la dynamique structurelle de ces écosystèmes côtiers pendant et après les activités de forages qui sont en cours de préparation.

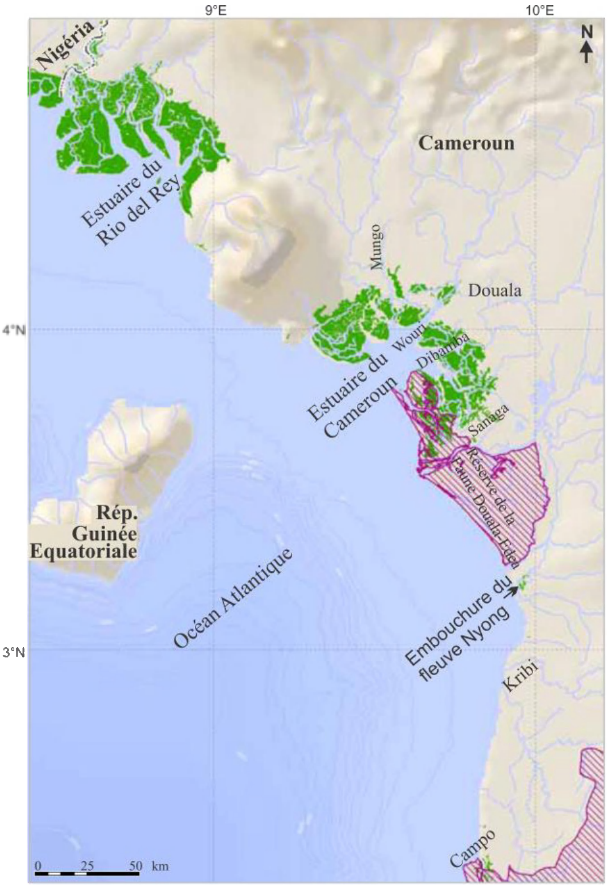

FIG. 1.5 Répartition des mangroves (couleur verte) le long de la marge atlantique du Cameroun (modifiée de UNEP 2007).

1.10.2 *Caractéristiques physiques de la zone d'étude*

Dans l'estuaire du Wouri (Douala, Cameroun), le climat est de type camerounien marqué par une longue saison de pluies (~9 mois) qui connait un pic de précipitation (~620 mm) pendant le mois d'août (Fig. 1.6 A). Par contre à Kribi, il est de type équatorial avec deux saisons de pluies et deux saisons sèches bien individualisées (Fig. 1.6 B). Il n'existe pas de station météorologique à l'embouchure du fleuve Nyong mais le climat de cette zone devrait vraisemblablement être intermédiaire aux deux types susmentionnés.

La température dans le Littoral et Sud-Cameroun est constante au cours de l'année et se situe autour de la valeur (~26°C) nécessaire à une croissance optimale des palétuviers. L'humidité relative de l'air est toujours voisine du taux de saturation.

En marée de vive-eau, le marnage atteint respectivement 2 m à l'estuaire du Cameroun, 1,2 m à l'embouchure du Nyong et 1,5 m à Kribi (Giresse *et al.*, 1996). Les fleuves côtiers tributaires de l'estuaire du Cameroun (Wouri, Dibamba, Sanaga), de l'embouchure du fleuve Nyong et de Kribi drainent des crues abondantes qui diluent considérablement la masse d'eau saline d'origine marine. Ces fleuves assurent également le transport d'importantes matières telluriques qui par sédimentation forment des vasières noires riches en matières organiques.

Du point de vue géomorphologique, ces drains hydrographiques sont facilités par l'existence d'un dénivellement entre la plaine côtière du Cameroun et les zones beaucoup plus internes (Olivry 1986). La structure de la forêt de mangroves dans ces plaines battues par les marées semi-diurnes est influencée par les facteurs abiotiques et biotiques.

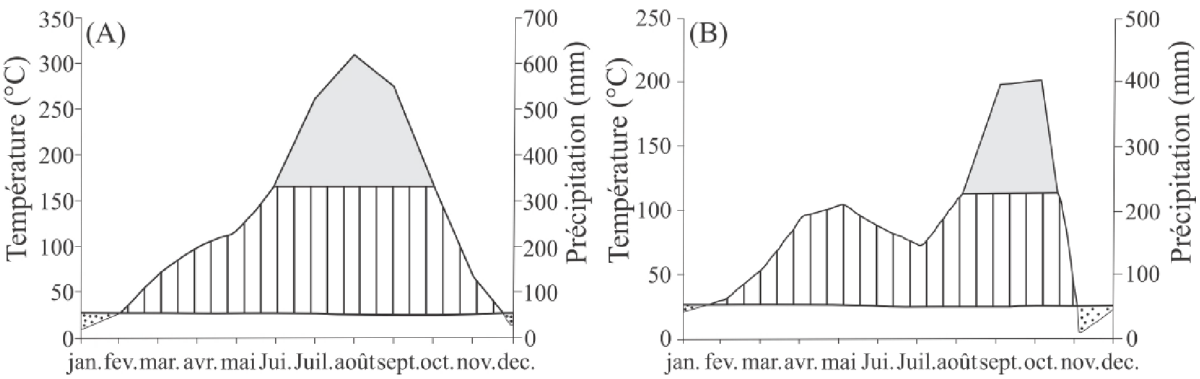

FIG. 1.6 Diagrammes ombrothermiques de (A) l'estuaire du Wouri (Douala, Cameroun) et (B) Kribi. Ce diagramme a été élaboré sur base des moyennes de précipitations et de températures de janvier 1961 à décembre 2009. La partie grise représente la période de fortes précipitations. La zone hachurée correspond à la période annuelle pendant laquelle la pluviométrie est en dessous de la moyenne mensuelle (~350 mm à l'estuaire du Wouri et ~230 mm à Kribi). La saison sèche (zones en pointillées) correspond à la période pendant laquelle la moyenne mensuelle de précipitation est en dessous de la moyenne mensuelle de température. Source principale: Direction de la Météorologie Nationale du Cameroun. Source complémentaire : http://www.tutiempo.net/en/climat/Douala_Obs/649100.htm; http://www.tutiempo.net/en/climat/Kribi_Obs/649100.htm.

1.10.3 *Forêts de mangrove du Littoral*

1.10.3.1 Mangrove de l'estuaire du Cameroun

L'estuaire du Cameroun est situé au cœur du Golfe de Guinée entre 9°16' - 9°52' de longitude Est et 3°40'- 4°11' de latitude Nord (Fig. 1.7). Il se trouve dans un contexte de baie abritée en arrière de cordons littoraux externes (Pointe Souélaba, île de Manoka, Cap Cameroun) (Baltzer *et al.*, 1995). Les palétuviers formant cette mangrove riveraine sont parcourus par un complexe de criques alimentées par les fleuves du Wouri, Mungo, Dibamba et Sanaga.

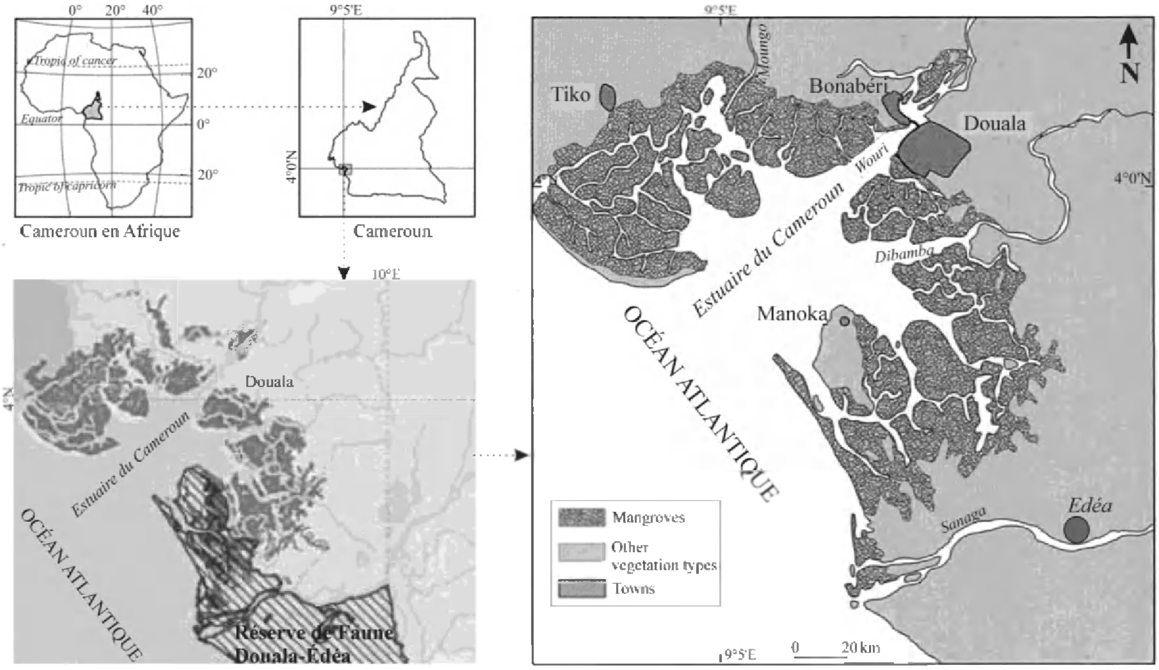

FIG. 1.7 Carte des mangroves de l'estuaire du Cameroun (modifiée de Din *et al.*, 2002; UNEP 2007).

La superficie du couvert végétal des peuplements de mangroves de l'estuaire du Cameroun a été estimée à environ 1100 km^2 (Spalding *et al.*, 1997). L'UNEP (2007) signale que celle-ci a considérablement régressé entre les années 2000 et 2006.

Trois paysages forestiers caractérisent les mangroves de l'estuaire du Cameroun (Din 1993; Baltzer *et al.*, 1995; Saenger & Bellan 1995; Din 2001).

1. A proximité des rives convexes (zones d'accrétion), l'on observe de véritables futaies monospécifiques à *Rhizophora racemosa* Meyer dont certains individus excèdent 40 m de hauteur. A l'intérieur de la forêt, cette espèce forme parfois des peuplements mixtes avec des *Avicennia germinans* géants à fûts rectilignes et larges (diamètre excédant parfois 100 cm), des *Laguncularia racemosa* (L.) Gaertn. f. matures et des fourrés de *Nypa fruticans*.
2. Partant des rives concaves (zones d'érosion) vers l'intérieur de la mangrove, l'on dénote une strate intermédiaire basse (hauteur $\leq$ 8 m) composée principalement des palétuviers rouges (*R. harrisonii* Leechman, *R. mangle* et *R. racemosa*) présentant un port nain et tortueux. Ces arbres se développent sur un substrat très consolidé et pauvre en dépôts alluviaux. L'essentiel des éléments photosynthétiques est utilisé dans la formation de nombreuses racines échasses arcboutées afin de maximiser l'absorption d'eau et des nutriments (Anthony 2004; Alongi 2009). Elles peuvent être accompagnées de diverses espèces typiques d'arrière-mangrove telles qu'*Hibiscus tiliaceus* L., *Acrostichum aureum* L., *Drepanocarpus lunatus* G. F. Meyer, *Dalbergia*

ecastaphyllum (L.) Taub., etc…

3. Au contact de la terre ferme, l'arrière-mangrove présente une physionomie d'une forêt marécageuse avec une hauteur de la canopée avoisinant 20 m. Cette zone se distingue facilement des deux précédentes par la présence notable de *Guibourtia demensei* (Harms) associée à *Phoenix reclinata* Jacq., *Raphia palma-pinus* (Gaertn.) Hutch., *A. aureum*, *H. tiliaceus*, *D. lunatus*, *D. ecastaphyllum*, *Conocarpus erectus* L., *Cynometra mannii* Oliv., *Ormocarpum verrucosum* P. Beauv., *Pandanus candelabrum* P. Beauv., *Annona glaba* L., *Anthocleista vogelii* Planch., et à quelques pieds de *Rhizophora* et *Avicennia*. Cette zone à inondation modérée fait souvent l'objet de diverses pratiques culturales lorsqu'elle est isolée par de hautes digues.

1.10.3.2 Anthropisation de la structure des mangroves de l'estuaire du Cameroun

L'homme est le plus souvent à l'origine de la modification structurale des paysages forestiers. L'intensité des actions exercées par ce dernier varie d'une région à une autre. Elle est plus accentuée dans l'estuaire du Cameroun à cause de sa proximité avec la première ville la plus peuplée du Cameroun qu'est Douala (2.510.283 habitants recensés en 2005) (MINEF 1996; MINEP 2004; Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009). En effet, la côte basse à mangroves qui borde la baie de Douala est soumise à diverses actions anthropiques. La coupe excessive des futaies dans certaines zones d'arrière-mangrove conduit généralement à la mise en place d'une végétation basse à port non dressée (obs. pers.). Ces fourrés denses à *H. tiliaceus* associées à *D. ecastaphyllum, A. aureum, D. lunatus, O. verrucosum*, etc... forment des touffes ombragées défavorables à l'établissement de nouvelles propagules. Par ailleurs, l'abattage accentué des palétuviers matures dans les vasières à submersion majeure ou intermédiaire laisse souvent entrevoir un paysage nouveau caractérisé par un couvert végétal ponctué par les trouées.

Dans les zones périurbaines, la présence de quelques reliques de palétuviers côtoyant les habitations précaires donne une idée des processus de transformations structurales qui se sont déroulés dans ces milieux encore inondables pendant les marées de très vives eaux. A côté de la coupe excessive et de l'urbanisation anarchique, l'exploitation des carrières de sables et de graviers sur les rivages pratiquée quotidiennement dans les marais de mangroves aux environs de Douala constitue aussi un phénomène destructeur de ces écosystèmes estuariens (MINEF1996). Cette activité anthropique en modifiant la structure et la texture des dépôts alluviaux limite fortement la régénération naturelle de la mangrove.

1.10.4 *Mangroves du Sud-Cameroun*

1.10.4.1 Embouchure du fleuve Nyong

A notre connaissance, un seul travail scientifique a jusqu'ici été réalisée dans les mangroves de l'embouchure du fleuve Nyong (Nfotabong Atheull 2008). En corollaire, la description que nous rapportons ci-dessous est basée uniquement sur l'étude susmentionnée et nos propres observations de terrain.

Le bassin du fleuve Nyong (Fig. 1.8) est en grande partie bordé par la grande forêt dense humide. Lorsqu'on parcourt ce fleuve de l'amont vers l'aval, l'on commence à observer les premiers palétuviers rouges à environ 1 km de l'embouchure (9°55'E et 3°15'N). Sur chaque berge, leur superficie s'accroît progressivement au fur et à mesure qu'on se rapproche de l'embouchure.

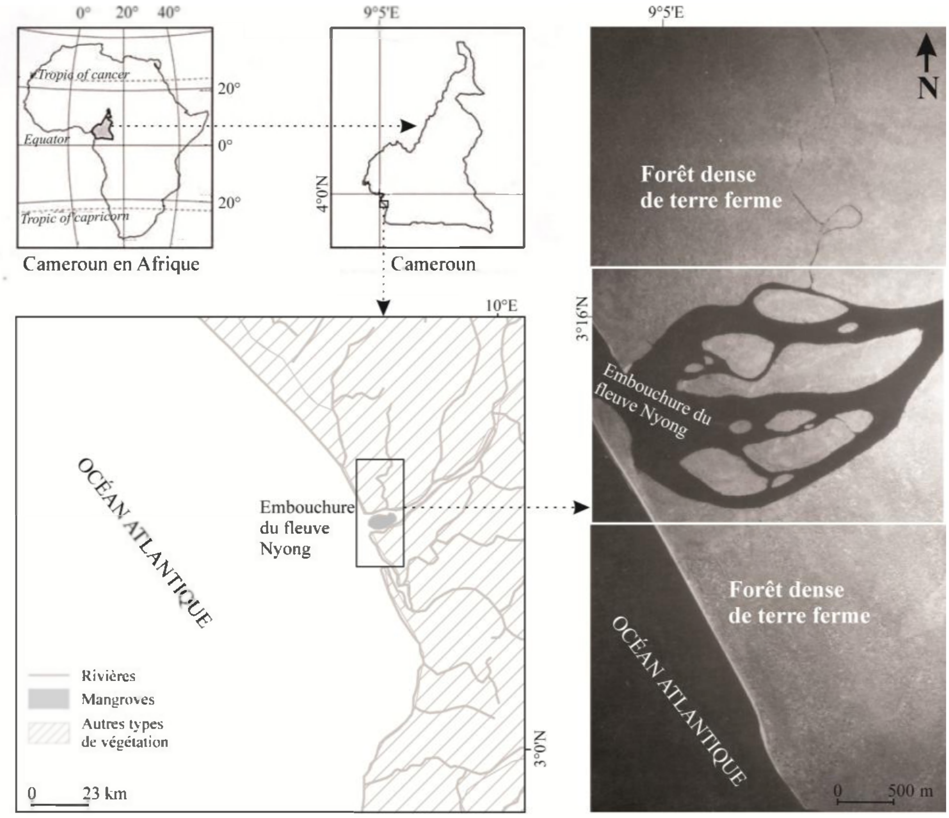

FIG. 1.8 Localisation des mangroves (traits blancs) de l'embouchure du fleuve Nyong (Cameroun). La photographie aérienne (année 1965) a été acquise auprès du Centre National de Cartographie du Cameroun.

Cette végétation sempervirente, composée de *R. racemosa* matures pouvant atteindre 18 m de hauteur, est adjacente aux espèces typiques d'arrière-mangrove ou des forêts de terre ferme. À la suite de cette flore, s'individualisent plusieurs îlots à *Rhizophora* bas (hauteur de cimes ~5 m) (Fig. 1.9). Le substrat de cette zone de mangroves est soumis à une érosion quotidienne.

FIG. 1.9 Îlots de mangroves à l'embouchure du fleuve Nyong (Sud-Cameroun).

1.10.4.2 Anthropisation de la structure des mangroves de l'embouchure du fleuve Nyong

La structure des mangroves de l'embouchure du fleuve Nyong est très peu impactée par les activités anthropiques (Nfotabong Atheull 2008). Plusieurs raisons peuvent expliquer ce faible degré de perturbations. De prime abord, cette forêt intertidale est soumise à de très faibles pressions anthropiques. En effet, les populations de pêcheurs installées dans les campements avoisinant cette végétation côtière n'exercent pas d'activités de fumage de poissons. Il faut rappeler ici que le bois de palétuviers rouges est très prisé pour le séchage du poisson à cause de sa grande teneur en résine et sa capacité à brûler à l'état frais (Walters *et al.*, 2008). Les produits de pêches sont généralement conservés pendant quelques jours dans les petites caisses contenant des blocs de glace et transportés vers les centres urbains en vue de leur commercialisation. Par ailleurs, la collecte de bois pour des besoins culinaires s'effectue généralement dans la forêt dense de terre ferme qui est adjacente à la mangrove.

1.10.4.3 Kribi

Les mangroves de Kribi sont situées entre 3°00' - 2°59' de latitude Nord et 9°54' - 9°58' de longitude Est. Les plus représentatives sont celles rencontrées dans les villages Mpalla et Nziou. Les mangroves de Mpalla (2°59'N - 9°55'E) sont alimentées en eau douce par de petits ruisseaux qui en fusionnant forment une petite rivière qui se jette dans l'Océan Atlantique. Son débit diminue considérablement pendant la grande saison sèche (novembre-février). À ce moment, l'alimentation en eau est principalement assurée par la marée. La flore est majoritairement composée de *R. racemosa* qui parfois s'accompagnent de *R. mangle*, *R. harrisonii* et *Avicennia germinans*, *Languncularia racemosa*, *Drepanocarpus lunatus*, *Ormocarpum verrucosum*, *Dalbergia ecastaphyllum*, *Ipomea pes carprae* (L.), *Guibourtia demeusei* et *Phoenix reclinata* (MINEP 2008). Les palétuviers rouges présentent un aspect juvénile à proximité de l'Océan qui tranche dans son arrière plan avec une mangrove mature adjacente à la forêt dense de terre ferme (Fig. 8.3 B). À Nziou (deux kilomètres au sud de Mpalla), s'observe sur les berges océaniques une mangrove structurellement fragmentée dont la composition se limite à quelques touffes à *Rhizophora* isolées les unes des autres.

1.10.4.4 Effets anthropiques sur la structure des mangroves de Kribi

La structure de la mangrove de Mpalla connaît des perturbations anthropiques modérées (MINEP 2008; Nfotabong Atheull 2008). La collecte de bois effectuée à petite échelle est très souvent sélective et concerne les troncs rectilignes de petits diamètres qui sont appropriés pour la construction des habitations précaires (obs. pers.). En dépit d'utiliser les palétuviers comme bois de chauffe, les populations riveraines collectent quotidiennement dans la forêt dense de terre ferme une essence (*Lophira alata* Banks) qui présente les même propriétés calorifiques que le palétuvier rouge. La mangrove de Nziou quant à elle a été fortement endommagée par l'installation des habitations modernes au bord de la mer (MINEP 2008).

1.11 RECHERCHE DANS LES MANGROVES AU CAMEROUN

En raison de leur accessibilité, les mangroves de l'estuaire du Cameroun sont celles qui ont été les plus étudiées. Din (1993) a effectué une étude botanique et écologique des mangroves de cet estuaire. Ensuite, Abata (1994), membre de l'équipe de Baltzer *et al.* (1995) a analysé la variation des paramètres édaphiques et a pu établir une classification sommaire des sols des mangroves de l'estuaire du Cameroun. Il démontre que les sols noirâtres riches en argiles et en limons (consistances fluides et sans litière) sont caractéristiques des zones pionnières. Ceux-ci sont précédés respectivement par des sols riches en litières (structure grumeleuse et présentent des taches brunes, rouges, gris foncé ou clair), les sols tourbeux à litière mince, à structure fibreuse et spongieuse très compacte et les sols plus continentaux à texture argileuse, à structure grumeleuse, de couleur brun foncé en surface et brun jaunâtre en profondeur. Le pH de ces sols est très variable entre deux phases successives d'engorgement (marée haute) et de dessication (marée basse). Baltzer *et al.* (1995) ont également montré que dans les mangroves de Douala, l'étude géomorphologique et sédimentologique, couplée à l'analyse d'images satellitaires permet de suivre et d'évaluer les effets anthropiques liés au développement portuaire, à l'érosion par les vagues de navires, à la pollution et à l'implantation d'un habitat précaire.

Par la suite, Tonye & Akono (1998) ont appréhendé les relations entre l'évolution des processus sédimentologiques et la dynamique naturelle des mangroves et ont corrélé les réponses radar aux paramètres de structure des mangroves. Ce qui leur a permis de faire des propositions en vue de mettre en place un système de suivi des écosystèmes littoraux. Celui-ci ne pourra être efficace que si l'on a une bonne connaissance de l'écosystème de mangroves.

C'est dans le même sens que Din (2001) décrit leur composition, leur fonctionnement, leurs caractéristiques physico-chimiques et biologiques et établit les affinités entre espèces caractéristiques ainsi que leurs relations avec les forêts voisines.

Dans l'estuaire du Cameroun, Din *et al.* (2001b) ont montré que les activités anthropiques constituaient la principale cause de dégradation de cette mangrove. La destruction de ces écosystèmes littoraux ne pouvant être compensée par une régénération naturelle, les connaissances concernant la croissance et la reproduction de ces arbres doivent être améliorées (Din *et al.*, 2002a).

Le développement des plantes de mangroves dépend aussi souvent des conditions abiotiques. Après avoir analysé les effets possibles des changements climatiques sur les mangroves de l'estuaire du Cameroun, Din *et al.* (2002a, b) soulignent que les variations interviendront dans la distribution spatiale des espèces caractéristiques.

Van Campo & Bengo (2004) ont obtenu la distribution moderne des grains de pollens et de spores des espèces des mangroves de l'estuaire du Cameroun et ont conclu que les pollens du genre *Rhizophora* sont les plus dominants. En effet, ce genre occupe une proportion et une valeur économique importante (Ndenecho 2007). Il est d'ailleurs soumis à une exploitation abusive (Din *et al.*, 2008). Ajonina (2008) dans sa contribution inventorie et modèle la dynamique des forêts de mangroves de la Réserve de la Faune de Douala-Edéa en suivant différents niveaux d'exploitation du bois de palétuviers. Dans cette même station, d'autres études supplémentaires montrent que les produits de mangroves sont majoritairement utilisés par les riverains pour des besoins de subsistance (Feka *et al.*, 2009; Nfotabong Atheull *et al.*, 2009).

1.12 PROBLÉMATIQUE

La réduction du couvert végétal des mangroves a été considérable au cours des deux dernières décennies (Spalding *et al.*, 1997; Barbier & Cox 2003; Duke *et al.*, 2007; Mmom & Arokoyu 2010; Polidoro *et al.*, 2010; Spalding *et al.*, 2010). Les diverses causes (naturelles et anthropiques) ainsi que les perspectives d'une disparition complète des forêts de mangroves ont été évoquées précédemment. Cependant, il est tout de même curieux de constater que très peu d'études scientifiques se sont focalisées sur l'évaluation et la prédiction des impacts anthropiques sur la structure de la mangrove (Sherman *et al.*, 2000; Dahdouh-Guebas *et al.*, 2002, 2004a; Obade *et al.*, 2009; Ambastha *et al.*, 2010).

De plus, au regard de la littérature existante sur les mangroves camerounaises, on constate qu'une seule étude scientifique a jusqu'ici été réalisée dans les mangroves de Kribi et de l'embouchure du fleuve Nyong (Nfotabong Atheull 2008). Les études intégrant les aspects d'utilisation et de dynamique des végétations de mangroves n'ont été réalisées que sur les stations non péri-urbaines situées à l'intérieur de la Réserve de Faune Douala-Edéa (Ajonina 2008; Feka *et al.*, 2009; Nfotabong Atheull *et al.*, 2009). L'étude de la structure des mangroves avoisinant la ville de Douala est inexistante. Pourtant, les pressions anthropiques qui sont exercées sur ces écosystèmes côtiers sont en perpétuelle croissance.

Généralement, les populations riveraines qui prélèvent au quotidien les ressources dans ces mangroves sont des pêcheurs. D'après le premier rapport du MINEF (1996), on dénombre environ 24.136 pêcheurs artisans repartis dans 205 villages et campements de pêche dans la zone côtière camerounaise. Ceux-ci ne sont pas avisés du rôle que les mangroves jouent dans la stabilisation de la zone côtière. En effet, se sont les forêts de palétuviers qui limitent l'érosion en amortissant les vagues naturelles issues respectivement des mouvements de masses océaniques ou des déplacements des pirogues et bateaux commerciaux (vagues artificielles). D'autre part, elles fixent d'importantes quantités de CO_2 libérées dans l'atmosphère par de nombreuses sociétés industrielles installées dans la capitale économique camerounaise qu'est Douala. Elles constituent également une zone relativement riche en produits halieutiques (MINEF 1996; MINEP 2008). En plus d'ignorer l'importance des mangroves, les riverains ne prennent pas en considération l'existence de la loi qui établit ces écosystèmes côtiers comme zones protégées. Cette étude permettra donc aux décideurs locaux de faire une mise au point complète du degré actuel d'anthropisation de la structure des écosystèmes de mangroves dans les régions du Littoral et Sud-Cameroun; ceci afin d'envisager la mise en place des mesures de gestion rationnelle.

1.13 OBJECTIFS ET QUESTIONS DE RECHERCHE

La gestion durable des écosystèmes côtiers tropicaux ne peut être efficiente sans la bonne compréhension des impacts directs ou indirects de l'homme (Dahdouh-Guebas 2002). Cette dernière requiert l'utilisation de plusieurs approches impliquant l'utilisation des données ethnobotaniques (enquêtes sur l'utilisation des ressources forestières), phytosociologiques (relevés de terrain), historiques (archives de cartes) et numériques (photographies aériennes et images satellites). L'application de cette approche multidisciplinaire constitue le cœur du présent travail. Du point de vue général, cette étude vise à analyser l'influence des diverses activités anthropiques sur la structure des mangroves de Kribi, de l'embouchure du fleuve Nyong et de l'estuaire du Cameroun. La bonne compréhension de ces phénomènes pourrait permettre une prédiction des capacités de régénération ou de colonisation de peuplement des mangroves perturbées. Pour atteindre notre objectif, nous avons examiné six questions de recherche.

QUESTION 1 (APPROCHE ETHNOBOTANIQUE): Quels sont les différents usages des produits forestiers ligneux collectés dans les mangroves de l'estuaire du Cameroun?

Les zones côtières sont parmi les régions les plus peuplées de la planète (Cohen *et al.*, 1997; Spalding *et al.*, 2010). Les populations qui s'y installent exploitent le plus souvent des ressources se trouvant dans l'environnement immédiat (Walters *et al.*, 2008). Sous l'effet de l'accroissement démographique, ces écosystèmes côtiers peuvent être soumis aux fortes pressions anthropiques résultant de leur utilisation abusive. Nous avons montré que le bois issu des mangroves était largement utilisé par les populations locales pour des besoins commerciaux et de subsistances.

QUESTION 2 (APPROCHE SOCIOLOGIQUE): La perception du degré de dégradation des forêts de palétuviers est-elle la même à l'estuaire du Cameroun qu'à Kribi (Mpalla) et l'embouchure du fleuve Nyong?

L'exploitation irrationnelle d'un écosystème modifie généralement sa structure. Puisque les observations des populations installées à proximité des mangroves peuvent s'étendre sur de longues périodes, ces dernières ont quelque fois la capacité de procurer des informations pertinentes sur certains aspects de changements environnementaux (Mitchel 1997; Kovacs 2000). Nous avons développé une approche basée sur la perception des résidents locaux afin de déceler les différentes activités anthropiques qui ont façonné la structure actuelle des mangroves.

QUESTION 3 (APPROCHE CARTOGRAPHIQUE): Quelle est la dynamique et la structure actuelle des mangroves périurbaines camerounaises?

Les photographies aériennes peuvent révéler des détails pertinents sur la dynamique structurale des forêts de mangroves (Dahdouh-Guebas 2002; Fromard *et al.*, 2004; Everitt *et al.*, 2010). À l'aide de Système d'Information Géographique (SIG), nous avons évalué l'évolution des mangroves périurbaines camerounaises sur les trois dernières décennies. Cette évaluation a été effectuée par le biais de trois séries de photographies aériennes (années 1974, 2003 et 2009), complété par des relevés de végétation réalisés à l'aide de la méthode PCQM+ (*Point-Centred Quarter Method*). L'analyse cartographique des photographies aériennes nous a permis de quantifier les pertes du couvert végétal et de mettre en évidence les différents niveaux de perturbation des mangroves périurbaines camerounaises. La méthode PCQM+ a rendu possible l'analyse des structures et des paramètres descriptifs classiques (structure diamétrique, densité, fréquences, surface terrière, etc…) de la mangrove résiduelle. La valeur d'importance (mesure relative de la contribution écologique de chaque espèce dans un écosystème) de chaque espèce a été estimée à partir des proportions relatives de certains paramètres descriptifs spécifiques tels que la densité, la fréquence et la surface terrière. Elle a permis d'ordonner les différentes espèces de mangroves par ordre de dominance. L'espèce présentant la valeur d'importance la plus élevée étant celle qui est dominante dans la communauté végétale.

QUESTION 4 (APPROCHE DYNAMIQUE): À l'estuaire du Cameroun, les activités de coupe des palétuviers s'effectuent sur quels types de structures forestières?

Nous avons poursuivi notre étude en reconstruisant la structure originale d'une mangrove actuellement perturbée (présence de souches et arbres sur pied). L'application d'une approche basée sur la reconstruction de l'indice de complexité de la mangrove (avant les activités de coupe) a révélé que les coupes de bois s'effectuent le plus souvent sur les forêts de palétuviers structurellement plus complexes. L'indice de complexité permet de charactériser le developpement structural d'une forêt (Holdridge *et al.*, 1971). Son estimation prend en compte le nombre d'espèces échantillonnées ainsi que leurs paramètres structuraux (densité, surface terrière et hauteur des arbres). Il permet une mesure objective du degré de complexité d'un écosystème forestier. La variation temporelle de cet indice est un indicateur des changements structuraux qui se sont déroulés dans la forêt de mangroves. Le scénario le plus plausible ayant conduit à la modification structurale du couvert végétal peut être décelé à l'aide d'un modèle individus-centré (modèle *KiWi*) (Berger & Hildenbrandt 2000). Les indices (biais, précision et exactitude) développés par Pretzsch *et al.* (2002) peuvent être adaptés et utilisés pour comparer la distribution des diamètres obtenue par simulation avec celle observée sur le terrain. Le biais représente la différence moyenne entre la distribution de diamètres simulés *versus* observés. L'indice de précision quant à lui indique la déviation standard des différences absolue ou relative entre les résultats issus du modèle et ceux observés sur le terrain. L'exactitude du modèle dénote le degré de convergence entre les données obtenues par modélisation et celles relevées sur le terrain. En somme, le scénario le plus plausible est celui qui présentera les faibles valeurs de biais, de précision et d'axactitude.

QUESTION 5 (APPROCHE STRUCTURALE): Comment se caractérise la structure des mangroves non périurbaines camerounaises?

Nous avons analysé la structure des mangroves non contigües aux zones urbaines. Nous avons développé une approche basée sur la signature de Fourier afin d'effectuer une classification des structures de mangroves non périurbaines camerounaises. Nous avons appliqué la méthode FOTO (FOurier-based Textural Ordination) (*cf.* Couteron *et al.*, 2006; Proisy *et al.*, 2007) sur une images QuickBird à très haute résolution. L'objectif étant de cartographier la distribution des diamètres, de biomasses et de stocks carbonés des mangroves sur une superficie de 2260 ha. La méthode FOTO intègre à la fois la transformation de Fourier de second ordre (2-D Fast Fourier Transform) et l'analyse en composantes principales (ACP). La mosaique d'images est découpée en plusieurs fenêtres qui sont soumises à la 2-D FFT. Chaque fenêtre est alors caractérisée pas son r-spectre de Fourier. L'application de l'ACP sur les r-spectres standardisés (centrés-normés) permet de réduire le nombre d'indices (coordonnées ACP) sur chaque fenêtre. Une équation allométrique reliant les indices de textures et les paramètres structuraux (diamètres) et fonctionnels (biomasses et stocks carbonés) peut donc être établie et utilisée pour cartagraphier la distribution de diamètres, biomasses et stocks carbonés des forêts de mangroves.

QUESTION 6 (APPROCHE SPATIALE): *Avicennia germinans* (L.) Stearn présente quel type de structure spatiale à l'estuaire du Cameroun?

Nous nous sommes focalisés sur une végétation monospécifique composée d'*Avicennia germinans*. Notons que c'est la seconde espèce dominante des forêts de palétuviers du Cameroun (*Rhizophora* spp. étant la première) et la moins exploitée par les populations locales. Nous avons appliqué une approche statistique basée sur la fonction *K* de Ripley pour analyser la structure spatiale d'*A. germinans* afin de déceler le rôle que cette espèce peut jouer dans les processus de recouvrement des zones dégradées. La méthode de Ripley se base sur les distances individuelles point par point pour analyser les structures spatiales à différents échelles (Ripley 1977; Diggle 1983; Goreaud & Pélissier 1999). Elle permet de comparer un motif ponctuel observé avec un motif obtenu par simulations (Besag & Diggle 1977). Elle combine la fonction *L* de Besag (1977) et la méthode de Monte Carlo (simulation d'un nombre considérable d'itérations). Cette dernière permet de générer des intervalles de confiance locaux pour un certain seuil de significativité généralement fixé à 1% ou 5%. Lorsque la courbe de distribution cumulative des fréquences d'observations point par point (fonction *K* de Ripley) se situe au dessus de la borne supérieure de l'intervalle de confiance, l'aggrégation des sémis de points devient significative à cette échelle de distance. Quand celle-ci se retrouve en dessous de la borne inférieure de l'enveloppe de confiance, la structure spatiale est qualifiée de régulière. La répartition spatiale des individus est aléatoire lorsque la fonction *K* de Ripley ne dépasse guère les bornes de l'intervalle de confiance.

PLANCHE 2. Commercialisation du bois de mangrove au marché Youpwe (Douala, Cameroun). À l'arrière, l'on peut observer un arbre non coupé d'*Avicennia germinans* (L.) Stearn ainsi qu'une très dense population de *Nypa fruticans* Thurnb. Wurmb.

PLATE 2. Commercialization of mangrove wood at the Youpwe market (Douala, Cameroon). Behind, one could denote a tree of *Avicennia germinans* (L.) Stearn and a very dense population of *Nypa fruticans* Thurnb. Wurmb.

CHAPTER 2

COMMERCIAL ACTIVITIES AND SUBSISTENCE UTILIZATION OF MANGROVE FORESTS AROUND THE WOURI ESTUARY AND THE DOUALA-EDEA RESERVE (CAMEROON)

ADOLPHE NFOTABONG ATHEULL[1,2*], NDONGO DIN[2], SIMON N. LONGONJE[3], NICO KOEDAM[3] AND FARID DAHDOUH-GUEBAS[1,3]

[1]Laboratoire de Complexité et Dynamique des Systèmes Tropicaux[‡], Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles - ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium,

[2]The University of Douala, Faculty of Science, Department of Botany, PO Box 8948 Douala, Cameroon.

[3]Biocomplexity Research Focus c/o Laboratory of Plant Biology and Nature Management, Faculteit Wetenschappen, Vrije Universiteit Brussels - VUB, Pleinlaan 2, B-1050 Brussels, Belgium

*Corresponding author

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[‡] Now called Laboratory of Systems Ecology and Resource Management

ABSTRACT

Worldwide there is growing research interest in the ethnobiology of mangrove forests. Notwithstanding that, little information has been published about ethnobiology of mangrove forests in Cameroon. The aims of this study were a) to analyze the harvesting methods and the local selling of mangrove wood products by loggers in the vicinity of Wouri estuary and b) to investigate the patterns of subsistence uses of mangrove wood products around the Douala-Edea reserve. Semi-structured interviews were conducted with 120 active mangrove loggers in 23 Douala wood markets and 103 households located in three villages (Mbiako, Yoyo I and Yoyo II) close to Douala-Edea reserve. In each of the three densely populated villages, every second household was chosen for sampling while in all markets, mangrove loggers were chosen randomly. In addition, log diameters were measured in each market using a wooden foldable tape measure. A *post hoc* analysis (Newman-Keuls test) was performed in order to detect the common wood class diameter sold in the Douala wood markets. The analysis of the loggers' survey data has shown that large logs of *Rhizophora* with diameter greater than 40 cm were common in the Douala wood markets and were more closely associated with loggers who used chainsaws. In addition to the general mangroves wood products selling, the analysis on a subsistence level (households' survey) suggests the local population's dependence on mangroves, with multiple uses of *Rhizophora racemosa* Meyer, *R. harrisonii* Leechman, *Avicennia germinans* L. Stearn., *Laguncularia racemosa* Gaertn. f. and *Conocarpus erectus* L. timbers for furniture, fences, smoking fish, and fuelwood. Finally, *Nypa fruticans* (Thunb.) Wurmb. leaves were used as thatching material for house walls and roofs. Our findings revealed that big logs of *Rhizophora* were commonly sold by the loggers. A majority of loggers (60%) reported that mangrove marketed wood constitute a principal source of income. Most of the villagers (85.83%) often depend on mangroves for subsistence needs and for them there is no substitute for mangrove wood. Therefore, more efforts should be undertaken at the national level to implement conservation, management and sustainable use of these coastal forests.

2.1 INTRODUCTION

Throughout the world, mangroves are among the most productive ecosystems because of their exceptional flora and fauna diversities (Tomlinson 1986; Baba *et al.*, 2002; Dahdouh-Guebas *et al.*, 2006; Duke *et al.*, 2007; Cannicci *et al.*, 2008; Nagelkerken *et al.*, 2008). These forested wetlands are socio-economically and ecologically important for local communities who use them amongst others as a source of wood and non-wood forest products or as a living space (Farnsworth & Ellison 1997; Rönnbäck 1999; Dahdouh-Guebas *et al.*, 2000a; Bosire *et al.*, 2008; Din *et al.*, 2008; Kristensen *et al.*, 2008; Walters *et al.*, 2008). They fulfil a habitat function for a variety of commercial fish and shellfish species that breed, spawn, hatch or develop in the mangrove. They also act as living dykes by protecting coastal communities against the effects of wind, waves and water currents. Despite the aforesaid roles of these coastal ecosystems, their annual loss rate is still high (about 3.6 million hectares has been lost since 1980) (Spalding *et al.*, 1997; FAO 2007; Duke *et al.*, 2007). To date coastal economic development still remains the main cause of global mangrove decline worldwide (Field 1999; Barbier & Cox 2003; Rist & Dahdouh-Guebas 2006; Barbier 2007; FAO 2007). The threats are significant since human migration into coastal zones is continuously increasing and the majority of people living in or near mangrove areas are poor (Walters *et al.*, 2008).

In Cameroon, very little attention is paid to mangrove forest management, despite the fact that this country has the third largest mangrove area in West-Africa after Nigeria and Senegal (Spalding *et al.*, 1997; UNEP 2007). In these countries, human disturbances caused severe damage to mangrove ecosystems and threaten them (UNEP 2007). Many disturbances are obvious (Farnsworth & Ellison 1997; Valiela *et al.*, 2001; Alongi 2002) and can be easily observed in some mature stands of Cameroon mangrove forests were variety of anthropogenic activities have largely modified the microtopography. This in turn may affect mangrove dispersion and establishment (Triest 2008), early development (Krauss *et al.*, 2008), growth (Komiyama *et al.*, 2008) or vegetation dynamics (Berger *et al.*, 2008). But some disturbances, such as cryptic ecological degradation (Dahdouh-Guebas *et al.*, 2005b), are particularly well hidden to show their terrible consequences only in case of natural hazards (Dahdouh-Guebas *et al.*, 2005a).

The high productivity (Teas 1977; Snedaker 1978; FAO 1994) and proximity of mangroves with large (sub)tropic urban centres has favoured human establishment in or near these lush forests, examples include cities such as Manila (Philippines), Colombo (Sri Lanka), Mombasa (Kenya), Banjul (The Gambia) and Douala (Cameroon). In the latter case, like elsewhere, patterns of harvest reflect the spatial distribution and relative accessibility of mangroves, which varies depending on local geomorphology and hydrology, socio-economic conditions and past human disturbance (Ewel *et al.*, 1998; Walters 2003). Although the dense prop-roots tend to make access to and clearing of mangrove forests difficult (Din *et al.*, 2008; Walters *et al.*, 2008), tree stems are still harvested and fisheries products collected there by local communities.

The overexploitation (cutting of several small and big trees in different stands) and clear-felling (clear cut of all trees in a larger area) of mangrove plants is rarely a fulltime occupation for local communities (FAO 1985; Kunstadter *et al*., 1986; Diop 1993; Lacerda 1993; Spalding *et al*., 1997; Glaser 2003; Walters 2005a; Lopez-Hoffman *et al*., 2006; Rönnbäck *et al*., 2007) but the use of chain saws in the logging operations is clearly the main factor that impacts mangrove cover in the Cameroon estuary (Din *et al*., 2008). Informal activities such as fishing, hunting (Walters *et al*., 2008), and sand and gravel extractions also contribute to the degradation of mangroves in this wetland ecosystem.

Although research suggests that harvesters are often flexible in their preferences (Walters 2003; Dahdouh-Guebas *et al*., 2006), high-scale mangrove logging (extensive cutting of big logs in different areas) encourage by the growing demand in wood products at Douala markets have led to heavily impacted stands within the mangrove forests. However, despite the complex relationship between coastal communities and mangrove, only few ethnobotanical surveys in mangroves of Cameroon estuary have been conducted (Din *et al*., 2008).

The present study was undertaken in the vicinity of Douala (Wouri estuary) and in three villages adjacent to the Douala-Edea reserve (Mbiako, Yoyo I and Yoyo II). The major objectives were (a) to analyze the harvesting methods and the local selling of mangrove wood products by loggers in the vicinity of Wouri estuary and (b) to provide understanding in the patterns of mangrove wood product utilization by local people (villagers) inhabiting the aforementioned villages. Attempts were also made to estimate the importance of mangrove for the local communities and to assess their perception on the evolution of mangrove forests during their life time.

2.2 METHODS

2.2.1 *Study area*

This study was conducted at Cameroon estuary, located in the Gulf of Guinea (3° 40'- 4° 11' N and 9° 16' - 9° 52' E). It is estimated that mangrove cover 1100 km^2 in this estuary (Fig. 2.1) (Spalding *et al*., 1997). Throughout the year, rainfall in the region is abundant (about 3988 mm) and the average annual temperature is high (26.7°C). The climate is of the particular equatorial type, so-called "*Cameroonian*" (Din *et al*., 2002a). Strong tidal influences on rivers (Wouri, Dibamba and Sanaga) and freshwater influxes enable mangroves to grow as far as 100 kilometres inland (Fig. 2.1) (UNEP 2007). Mangroves around Douala, Mbiako, Yoyo I and Yoyo II often appear as dense and big trees with a canopy reaching 30-40 metres in height. Cameroon's estuary mangrove forests are continuously under higher human pressure because of the increasing demographic patterns in the adjacent urban areas like Douala where the total number of active loggers has been estimated to be 350 (Din *et al*., 2008).

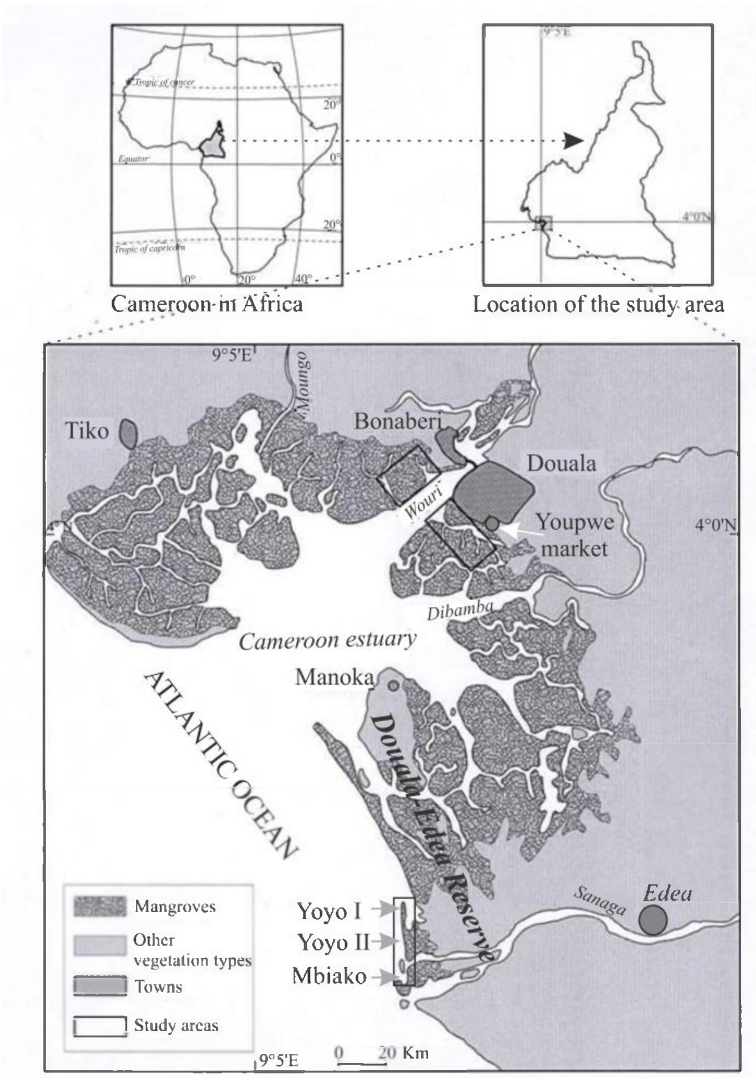

FIG. 2.1 Mangrove of the Cameroon Estuary (modified from Din *et al.*, 2002a).

There were no official statistics available about the village populations of our study area. Nevertheless, the village chiefs estimated this number to be about 1,845. Although we acknowledge that this number is relatively low, the human disturbance is continually greater in the mangrove forests close to Mbiako, Yoyo I and Yoyo II villages. The latter villages were selected because of their vicinity and strong interaction between their relative dense communities and the mangrove forest. Whereas Yoyo II and Mbiako sites are characterized by a medium size, the Yoyo I village is much stretched. Consequently, this has led to a variation of sample size in different villages (22 in Mbiako, 54 in Yoyo I and 27 in Yoyo II).

2.2.2 *Loggers' survey*

The first field trip was carried out in November 1999 and March 2000 in 23 Douala wood markets. The logger survey sheets comprised eight sections (Table 2.1). Questionnaires were of semi-structured type (Dahdouh-Guebas *et al.*, 2000) with short proposed answers or free open answers. In the surveyed wood markets, mangrove loggers were chosen randomly. In case where informants chosen were the resellers (in a few case, some loggers delivered big logs to various resellers who are often paid by the loggers after the sale), we often recorded information from the logger who has engaged the reseller. This procedure was pursued since loggers were often the vendors and therefore mostly indicated to provide both responses regarding harvesting and wood selling (the price of marketed wood is usually defined by the loggers). A total of 120 active mangrove loggers (comprise of only men) were interviewed. Based on the total number of loggers existing in the population (Din *et al.*, 2008), we assumed that 34.28% of active loggers were surveyed. In addition to survey, we asked the loggers for permission to measure the diameter of logs by using a wooden foldable tape measure. By doing so, we also estimated the length of the logs.

Table 2.1 Broad sections of topics constituted of clusters of questions dealing with these topics for mangrove loggers in 23 urban wood markets in Douala.

A. Survey with loggers	
A1. The social situation (the agreement of the surveyed logger is mandatory) allows the logger to be identified, details his/her past, present and future activities, and the sources of energy he/she is using. This was asked at the end of each interview.	**A2.** The localization of the exploitation site which concerns at the same time the fuel wood logging points in the field, and the markets in which the produce is sold;
A3. The resources used provide information on the tools the mangroves loggers possess and/or use during their activity, including such tools as canoes, engine-powered canoes or boats, chain saws, carpenter saws, machetes, axes, etc.;	**A4.** The daily production is a set of raw numbers provided by each logger. This is the fundamental part of this survey that should provide answers about deforestation and estimates the economic value of the mangrove wood resources. It specifies the targeted species, provides the number of trees logged in the field, usually the length of the used part of the fallen tree, as an alternative to the knowledge of the tree heights, the number of logs obtained and their diameter, and the transported quantity. The surveyor did not adjust or modify the information obtained from the mangrove loggers.
A5. The expenditures of the mangrove logger shed light on the overall necessary resources for the accomplishment of this activity. They concern the equipment that he/she can rent or the labour used, the cost of food eaten in the field, different types of fuels, etc;	**A6.** The daily incomes of the mangrove logger are inferred from the answers received on the average quantities of daily sales in the market, while taking into account the eventual price fluctuations of all the markets according to the universal law of demand and supply;
A7. The monthly revenues are a statement provided by the mangrove logger, without any relation with the aforementioned revenues and expenditures;	**A8.** The role of the mangrove is restricted to a unique question that concerns the environmental knowledge of the mangrove logger.

2.2.3 *Households' survey*

The second field survey was carried out between February and March 2002 in three villages near the Douala-Edea reserve: Mbiako (3°30'N, 9°39'E), Yoyo I (3°38'N, 9°38'E) and Yoyo II (3°40'N, 9°38'E). The questionnaire sheets contained seven sections (Table 2.2).

The survey was done amongst regular inhabitants in the three aforementioned villages by conducting interviews using semi-structured questionnaires with 103 villagers (comprised of men or women representing a household).

Table 2.2 Second sections of topics constituted of clusters of questions dealing with these topics for mangrove villagers in three villages adjacent to the Douala-Edea reserve.

B. Survey with villagers	
B1. Socio-demographic and economic attributes of the villager (incl. age, religion, marital status, household composition, years of life in village, profession, family income source, and assets of the family). This was asked at the end of each interview.	**B2.** An objective assessment of the interviewee's knowledge on mangroves (in the text referred to as 'mangrove knowledge') was made by asking the person to identify which mangroves were around using plants parts freshly collected from the field and scoring the correctness as described by Dahdouh-Guebas *et al.* (2000a).
B3. The general utilisation of mangroves gave a first idea of uses in general. Although no further focus, here we inquired also for non-wood forest product uses such as medicinal or alimentary utilization of the mangrove.	**B4.** Detailed questions on fuelwood use, investigating genera used, their quality, their part and size used. We also asked for reasons of use and for any alternative fuelwood uses. Who and how much was used was also part of the survey.
B5. The same was repeated for construction and service wood.	**B6.** The same was repeated for fine timber (for furniture, crafts and arts).
B7. Personal assessment of the interviewee's perception on changes in the mangrove forest was gained by asking questions on change in area, in mangrove species composition and on opinion reasons for this. We also asked them about their opinion of the future.	

In each village, households were considered as basic sampling units. In order to avoid repetition from members of the same household, only one person per household was surveyed (Dahdouh-Guebas *et al.*, 2000a). Over the three densely populated villages, every second household was chosen for sampling. However, information was not recorded in the all households that were chosen because of uncomfortable reception or hostility. In this case and when information gathered in the previous household was incoherent, we sampled in the adjacent one.

In each of the households sampled (103), the average number of persons was 4.65 ± 2.16. Based on total population estimates from the Village Chiefs (Table 2.3), we calculated that the total number of households of Mbiako, Yoyo I and Yoyo II was about 132, 158 and 86, respectively. Therefore 16.66%, 34.17% and 31.39% of households were sampled at Mbiako, Yoyo I and Yoyo II, respectively. We draw the attention to the second section (Table 2.2 B2) which investigates each respondent's knowledge on mangroves, hereafter referred to as 'mangrove knowledge'.

Table 2.3 Descriptive statistics of the total population structure within the villages surveyed (a), marital status (b) and profession (c) of the respondents. The values in parentheses indicate percentages per village or for all villages together (Total) for a particular demographic factor. Note that they do not always necessarily add up to 100 %.

	Mbiako	Yoyo I	Yoyo II	Total
Number of questionnaires	22	54	27	103
Socio-demographic factors				
(a) Population structure (based on total population statistics from the Village Chiefs)				
Adult Male	294	240	87	621
Adult Female	108	264	120	492
Child	213	234	195	732
(b) Marital status of respondents				
Married	11 (50 %)	29 (54 %)	16 (59 %)	56 (54 %)
Bachelor	7 (32 %)	20 (37 %)	8 (30 %)	35 (34 %)
Widow	4 (18 %)	5 (9 %)	3 (11 %)	12 (12 %)
(c) Profession of respondents				
Business	8 (5 %)	12 (22 %)	7 (26 %)	27 (26 %)
Fishing	16 (73 %)	38 (70 %)	15 (56 %)	64 (62 %)
Smoking fish	11 (50 %)	41 (76 %)	17 (63 %)	74 (72 %)
Other (*e.g.* teaching, *ad interim* jobs)	1 (5 %)	2 (9 %)	0 (0 %)	3 (3 %)

2.2.4 *Analysis of the loggers' survey*

Quantitative and qualitative data provided by loggers were encoded and analyzed differently.

2.2.4.1 Quantitative analysis

The loggers' age, ranging from 20 to 69 years old, was split into five equal classes according to a normal distribution. The first and fifth classes refer to youngsters and elderly, respectively, whereas the three others classes were found to comprise (middle-aged) adults (see results). The years of experience in logging activities were also divided in four classes of 10 years interval based on socio-economic criteria. The criterion was the 1990s (10 years before we sampled) economic crisis that has led to the increasing human migration toward cities such as Douala (Cameroon) which is adjacent to mangrove forests. One-way ANOVA was performed to determine the difference in monthly income between age classes and wood diameter classes. This statistical analysis was most preferable as we were dealing with comparisons of more than two quantitative data. A *post hoc* analysis was afterward done with Newman-Keuls test to detect the common wood class diameter sold in the markets. Differences between wood quantities cut down and the one transported to the market were also analysed using the Student t-test.

2.2.4.2 Qualitative analysis

The exploitation equipment is a determinant for the size, quality and number of the trees that can be cut down by loggers. Different materials used for mangrove deforestation have been identified during the survey and their classification has been made in relation to their acquisition mode (owned, shared or rented). Therefore, impact of this equipment on the mangrove degradation and household income can be appreciated. Information concerning the diverse form of wood sold, the different people involved and their years of experience in this commercial activity were provided by respondents encountered in each market.

2.2.5 *Analysis of the villagers' survey*

Because of the different nature of the purpose in the surveys, the villagers' survey was not analysed in the same way as the loggers' survey. The villagers' survey was primarily descriptive, but some relevant answers were confronted with the mangrove knowledge of the respondents.

2.3 RESULTS

During fieldwork, loggers and villagers were relatively open to provide information about resource extraction patterns and changes that have occurred within mangroves. Nevertheless, the accuracy of responses was considered significant when they were able to identify mangrove species.

2.3.1 *Loggers' survey*

2.3.1.1 Mangrove wood sale

The age of mangrove sellers ranges from 20 to 67 years with average of 45 ± 8 years. Among them (120 loggers), 60% considered marketed woods as their principal source of income. Likewise, about 19% of these loggers were currently involved in informal job practices such as railway workers, mechanics, motorcycle drivers, bricklayers, security guard agents, charcoal makers and soap manufacturers. Their entire income was used to ease the household expenditures. Thirty-eight percent (38%) of loggers interviewed, mostly young people awaiting a formal job, sold mangrove wood temporarily. Only 2% of mangrove loggers were retired. They often used revenues provided by mangrove products in complement to their retirement allowance.

The loggers reported that mangrove logs were often taken in stands that were closer to the city and easiest to access by creek. Large and small *Rhizophora racemosa* Meyer and *R. harrisonii* Leechman timbers, cut down with chain saws or machetes and carpenter saws respectively, were commonly transported towards the local wood markets using traditional boats (Fig. 2.2 A).

FIG. 2.2 (A) Unloading of mangrove wood near the Douala wood market (Youpwe). (B) Mid-size logs and small timbers commercialized at the Douala wood markets. (C) Big marketed logs at the Douala wood markets (D). (Photograph by ANA). Transformation of big logs into heaps (this wood is sold at local markets *e.g.* near the Wouri bridge). (Photograph by ND).

At the markets, only logs with diameter < 40 cm were traded in form of heaps. A heap of 3 logs (equal to a cubic meter) with a length of 60 cm and a diameter comprised between 20-40 cm cost 2.85 € (in the 1999s, 1 € = 655.95 FCFA or Cameroon Franc) (Fig. 2.2 B, on the left) while 10-15 logs assembled (equal to a cubic meter) with a length comprise between 60-80 cm and a diameter < 20 cm cost about 2.30 € (Fig. 2 B, on the right). On the other hand, a large log with a length of 35 cm and a diameter greater than 40 cm (Fig. 2.2 C) cost about 4.60-7.62 € (this price was equal to 3000 - 5000 FCFA). Big logs bought were often transported towards the centre of Douala for selling or heating of the henhouse. In some cases, however, logs were split into pieces and afterward assembled in form of small heap for sale (Fig. 2.2 D). A heap of four mangrove wood pieces cost on average 0.20 ± 0.019 €. It was used by the buyer for cooking, heating or making charcoal.

In the vicinity of Douala, the trade of mangrove wood products is common. The loggers have declared average monthly revenues in the order of 98 ± 61.41 €. There were not significant differences of average monthly income between logger age classes ($F = 1.14$; d.f. = 4; $p = 0.34$) (Fig. 2.3 A).

However the average quantity of wood transported to market by loggers of the fifth age class was significantly lower than that of the others age classes ($F = 2.55$; d.f. = 4; $p = 0.04$). Further statistical analysis also revealed that mangrove wood diameter of the third class was significantly more sold at wood market than the one of the first class ($t = 7.63$; d.f. = 73; p <

0.0001) and the second class (t = -6.71; d.f. = 91; p < 0.0001) (Fig. 2.3 B).

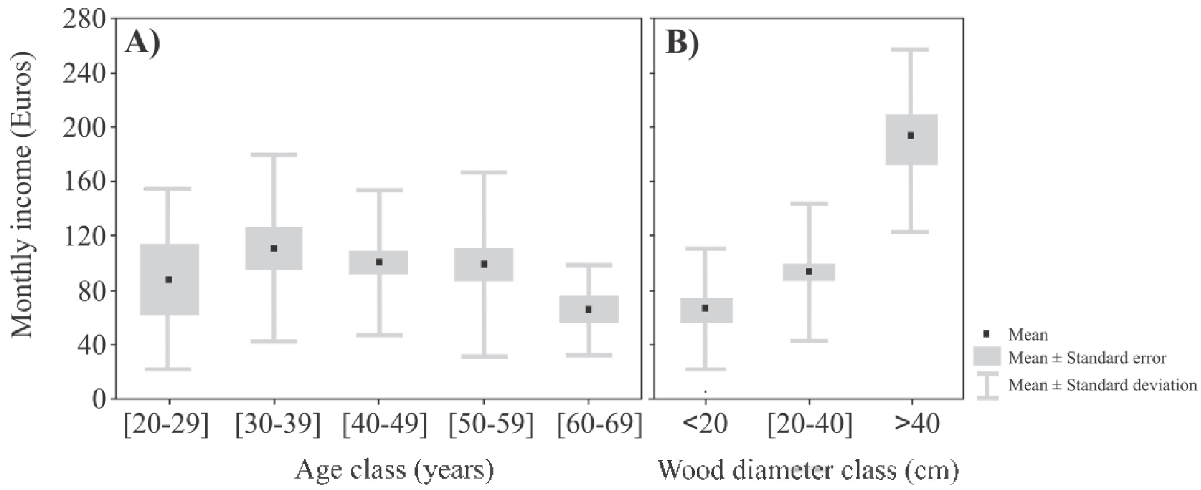

FIG. 2.3 (A) Repartition of loggers' monthly income between age classes. Elementary statistical analysis also showed that average monthly income of the third class was not significantly different from the one of the first class (t = 0.48; d.f. = 51; p = 0.62), the second class (t = -1.02; d.f. = 66; p = 0.30), the fourth class (t = -1.44; d.f. = 45; p = 0.15) and the fifth class (t = -1.44; d.f. = 45; p = 0.15). (B) Relation between revenues and wood diameter sold at all markets visited.

2.3.1.2 Diameter of mangrove wood at markets

During cutting of logs, loggers often used chain saws to cut down large trunks whereas carpenter saws and machetes were used when harvesting small and tall trees (Table 2.4).

Table 2.4 Acquisition mode of exploitation materials used for wood cutting in Cameroon estuary and their impact on mangrove degradation and household income.

Equipment		Acquisition mode		Impact on	
	Users number	Owners	Rented	Mangrove degradation	Household income
Boat	120	94 (78.33 %)	26 (21.6)	Average	Positive
Chain saws	31	18 (58.1 %)	13 (41.9)	Very high	Positive
Carpenter saws	103	103 (100 %)	0 (0 %)	High	Positive
Machetes	120	120 (100)	0 (0 %)	Little	Insignificant

The need of loggers to increase the household income thrusts them to claim or rent this kind of equipment. The average diameter and length of the logs were 41.36 ± 11.92 cm and 43.28 ± 12.26 cm, respectively. The survey revealed that there was a highly significant difference between diameter classes of wood exploited (F = 12; d.f. = 2; p = 0.000018) (Fig. 2.4).

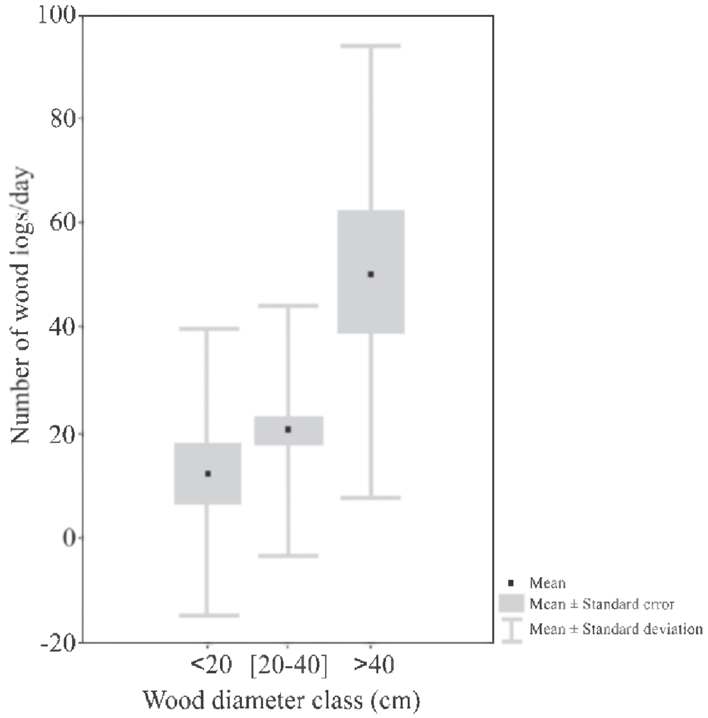

FIG. 2.4 Box and whisker showing the reparation of the number of wood logs and their diameter.

A *post-hoc* analysis (Newman-Keuls test) showed that trees with an average class diameter greater than 40 cm were preferred over the two others classes which were all harvested in the same way (Fig. 2.5).

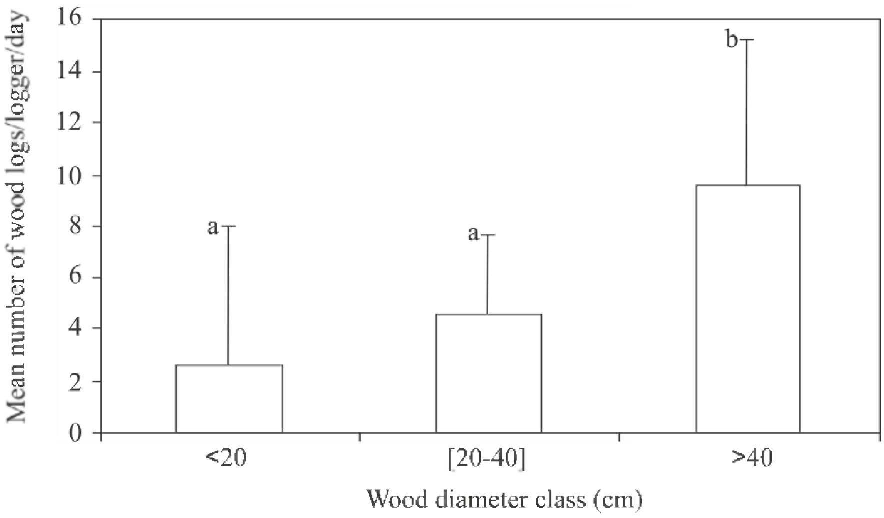

FIG. 2.5 Histogram of the average number of trunks cut down and their diameter class (the vertical bars indicate the standard deviation whereas the letters differentiate between wood diameter classes most exploited (b) and less exploited (a)).

Although big logs were uncommon outside the regular wood markets, the largest diameters of wood products were found with the loggers who use chain saws.

Five trees on average (4.75 ± 4.36) were cut down daily by each harvester. *Rhizophora racemosa* was heavily harvested because of its availability, dominance and suitability for making firewood and charcoal. On the other hand, in regard to the diameter of wood products, mangrove logging was often non-selective. Many small timbers of *Rhizophora* spp., often used as building material, were also found in the local markets. The same was true for species such as *Conocarpus erectus* L. and *Avicennia germinans* L. Stearn. Generally, the entire quantity of wood harvested was not transported to the market on a daily basis. Nonetheless, only a small amount of large trunks were left in the field. Therefore, the average quantity of wood logs by loggers was not significantly different from the one transported at the market ($t = 1.38$; d.f. = 17; $p = 0.18$).

2.3.1.3 Years of experience in logging activities

Since the loggers were not involved in logging every day, their years of experience in this activity were considered as relative. We did not find differences in quantity of wood logs between years of experience classes ($F = 0.32$; d.f. = 2; $p = 0.72$) (Fig. 2.6).

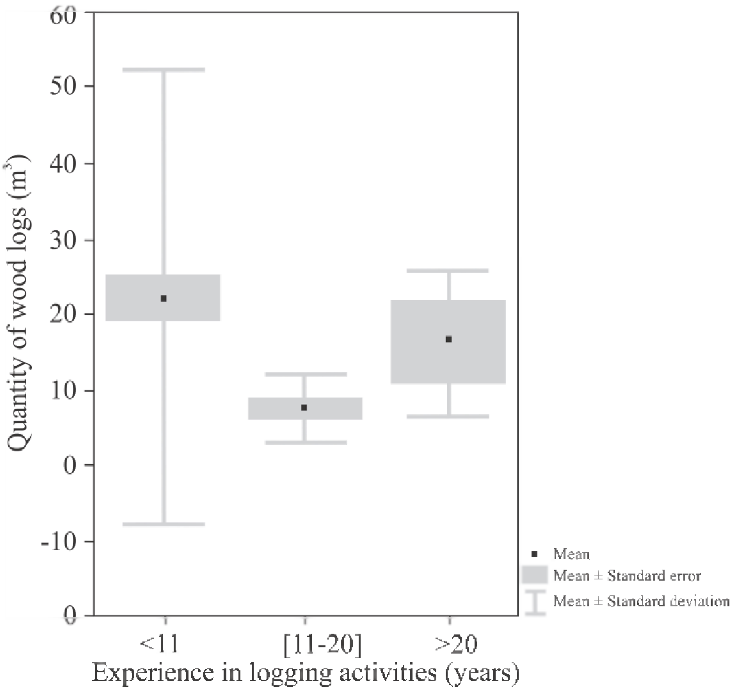

FIG. 2.6 Distribution of the quantity of wood logs according to experience in logging activities.

Although local forest users with greater experience (more than 10 years) in logging (Fig. 2.7 A) were less represented (15/120), they were more likely able to know where stands with large trunks could be found. Furthermore, their skills during handling operation and boat manipulation allowed them to heavily collect mangrove wood products. However, most of the loggers (105/120) have been harvesting mangrove wood for 10 years (Fig. 2.7 A). They were found to be adults and their physical strengths allowed them to widely over-cut mangroves. Amongst them, 43.82% were between 40 and 50 years old (Fig. 2.7 B). While carrying out logging activities, they were looking for alternative jobs and were willing to abandon wood harvesting if they were hired elsewhere. On the order hand, 18.09% (19/105) and 25.71% (27/105) of loggers with 10 years of experience belonged to the second (30-39 years) and the fourth (50-59 years) age classes, respectively. Only 6.67% of loggers were youngsters (20-29 years) and 5.71% were in the elderly class (60-69 years).

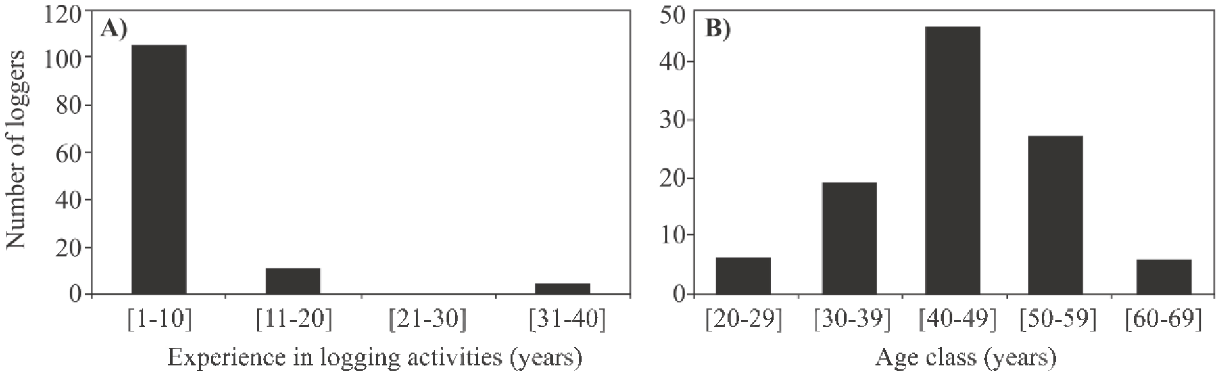

FIG. 2.7 (A) Repartition of loggers between logging experience classes. (B) Distribution of loggers with ten years of experience in logging activities and their average income by age groups.

2.3.2 *Villagers' survey*

2.3.2.1 Ethno-botanical knowledge of mangroves

The majority of respondents was married and was mostly involved in fishing, fish smoking or both (Table 2.3). Understanding the respondents' mangrove knowledge was the initial step to make sure data interpretation was sound. There was a group of respondents who had expert mangrove knowledge about the different species of mangroves and were able to describe them by leaf structure, bark and flowers separately. This category represents 10% of the survey. Another group, the majority (50%), could only distinguish between mangrove species by describing the leaves, and we term them as having a 'good working knowledge'. Yet, another group of respondents could make distinction between mangroves when assisted by samples of the species (26%). The final group had no idea about mangrove species, but they knew what the mangrove forest was (14%). However, they were unable of describing their characteristics.

2.3.2.2 General utilization of mangroves

Five villagers interviewed were also loggers. They were native people and were not involved in marketed woods. About 3 trees were cut weekly by each villager for domestic use. The different mangrove species present had different uses. *Avicennia germinans* was used for furniture, fencing poles, fuelwood for cooking and smoking fish, bed poles, timber poles for *banda* (table-like construction to smoke fish) construction, canoe anchors, paddles and fishing traps (Table 2.5).

Table 2.5 Subsistence uses of mangrove by local people around three villages (Mbiako, Yoyo I and Yoyo II) established within Cameroon estuary.

Taxa name	Part used	Uses
Rhizophora spp.	Young, mature and old stems, branches	Fuelwood (cooking and smoking fish), furniture, fencing poles, fuelwood for cooking and smoking fish, bed poles, timber poles for *banda* construction, canoe anchors, paddles and fishing traps bridges
Avicennia germinans	Young, mature and old stems, branches	Fuelwood (cooking and smoking fish), furniture, fencing poles, fuelwood for cooking and smoking fish, bed poles, timber poles for *banda* construction, canoe anchors, paddles and fishing traps
Laguncularia racemosa	Stems	Firewood (home use), smoking fish, poles for furniture and fences,
Conocarpus erectus	Stems	Firewood (home use), smoking fish, poles for furniture and fences,
Nypa fruticans	Leaves	Thatching material for house walls and roofs

Young, mature and old stems were used for this, and so were branches. The same parts were used from *Rhizophora racemosa* and *R. harrisonii* for the same purposes (Fig. 2.8 A, B).

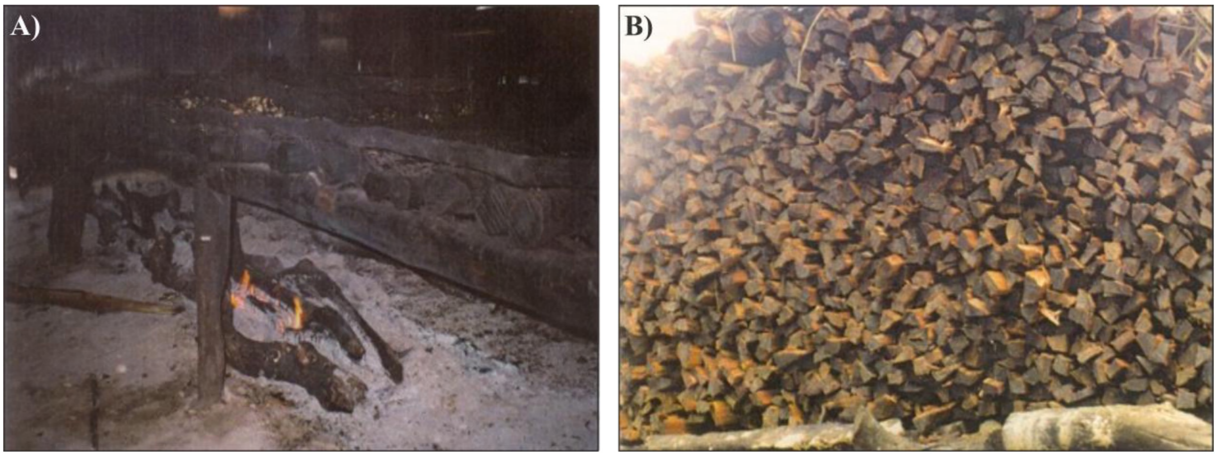

FIG. 2.8 (A) *Banda*, used to smoke fish on. (B) Stacks of mangrove wood ready to be used as *banda* and to be burnt for smoking the fish. Mangrove wood is thus used to construct the table-like *banda* but also to burn and smoke the fish itself. (These photographs were taken at Yoyo I by SNL).

In addition, they used *Rhizophora* spp. poles for bridges. Stems of *Laguncularia racemosa* Gaertn. f. and *Conocarpus erectus* were used as fuelwood for home use and for smoking fish, and as poles for furniture and fences. Finally, *Nypa fruticans* (Thunb.) Wurmb. leaves were used as thatching material for house walls and roofs. The most common use of mangroves was for fuelwood (Fig. 2.9 A), which was particularly true for *Rhizophora* spp. because of their availability, and their slow, highly calorific and smokeless burning properties. Within the two construction uses, *i.e. banda* timber and construction wood, *Rhizophora* spp. and *Avicennia germinans* have a significantly higher preference than *Conocarpus erectus* (Fig. 2.9 B). The majority of the respondents (101 over 103) indicated that there was no substitute for mangrove wood or at least they did not know about it.

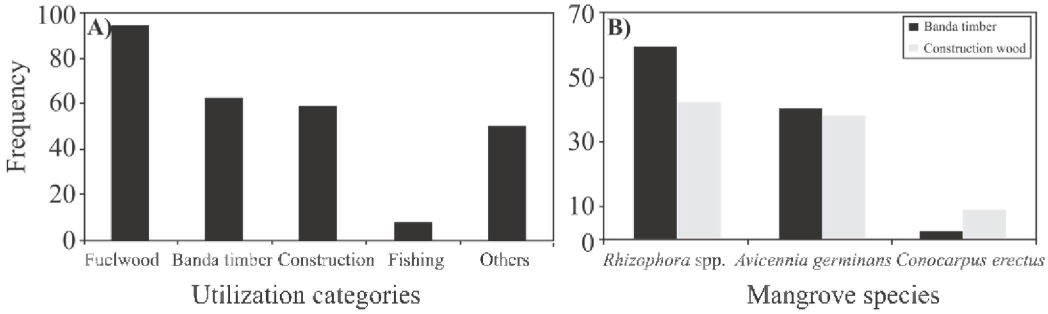

FIG. 2.9 (A) Utilization frequency of different mangrove use categories around the Douala-Edea reserve. (B) Mangrove species used in construction, either as *banda* timber (black) or as construction wood (grey). (The genus *Rhizophora* mostly used is represented by *R. racemosa* and *R. harrisonii*).

2.3.3 *Perception on changes in the mangrove*

When asked whether the mangrove was very, little or not important, a wide range of respondents (87%) with expert and good mangrove knowledge answered that the ecosystem was of prime importance. Nevertheless, fifty six percent of the respondents reported that there was a negative change in the mangrove. Among them, 60% indicated that the decline was serious and 40% reported that it was average. Respondents related the decline to selective harvesting and uncontrolled deforestation. It was reported that every family has the right to harvest mangrove wood at anytime, anywhere and in any quantity. However, this appeared to be just a perception as Cameroon legislation protects mangroves as a particular ecosystem (Frame-law n°96/012 relative to management of environment in Cameroon, August 5th 1996). Others maintained that local population growth and the resulting pressure on coastal zone have led to a decrease in the extent of mangrove area. Interestingly, one respondent reported that due to a lack of adequate technology most of the heat produced during fish smoking is wasted.

2.4 DISCUSSION

2.4.1 *Commercial uses*

The mangroves of Cameroon are under legal protection but this has not effectively precluded local residents from continuing to harvest them since the protective law is not well enforced. The rapid growth of human populations and the resulting pressure on coastal environments often lead to uncontrolled logging, posing severe threats to the mangroves (FAO 2007). Negative change rates in the extent of mangrove surface area of this region have been reportedly aforementioned. As in Indonesia, commercial exploitation of mangrove wood has been important and therefore considered as one of the current threats (FAO 2007). Besides extensive felling of mangrove plants in the Wouri estuary, oil and solid pollution also negatively affect the health and quality of the stands. Some examples have been found in the Manoka bay (southern Cameroon) where, even though banned, mangroves have undergone an industrial exploitation at the dawn of last century (Hedin 1928). The signs reminding of this activity are still visible to date especially were a wood processing plant and the port for export was located (Din *et al.*, 2008).

On the other hand, however, exploitation of mangroves in the Wouri estuary was an activity predominantly undertaken by local residents. These coastal ecosystems are traditionally used for the production of firewood, charcoal, boats, fish-traps, timber and poles for houses. The commercial exploitation of mangrove wood products around the Wouri estuary is local, common and well-developed. For instance, sales of mangrove wood were consistently observed at all markets visited. Large mangrove timbers, usually harvested with chain saws, are transported to the market using traditional boats (non-engine-powered canoes). In spite of drowning risk, low swimming ability of loggers and lack of protective material (life vests) most of harvesters interviewed (60%) were not disheartened because marketed wood appears to be very important for their livelihood. Although their revenues were not considered significant, they found no serious reasons to switch to another activity.

In the framework of this study, adult loggers involved in the mangrove harvesting considered commercial exploitation of mangroves as a mean of poverty alleviation because of its high economic return. However, this does not apply to younger loggers who were willing to abandon logging because of difficulties (drowning risk, removal of logging sites, transport effort) associated to this activity. The average monthly income is given in the results section. If based on the so-termed US$1/day, loggers were not poor. However, consumers established near local markets (*e.g.*, Youpwe market) were unable to pay for mangrove wood since their purchasing power was low (pers. obs.). Therefore, they were often involved in logging to meet domestic fuel and construction needs. This contributes to a relative progression of the mangrove loggers around the Wouri estuary. The same report is true for many coastal communities worldwide which are currently characterized by chronic poverty (Kunstadter *et al.*, 1986; Walters 2003; FAO 2007; Din *et al.*, 2008; Walters *et al.*, 2008). Din & Blasco (1998) reported that harvesting has become more efficient because of the introduction of slicers and large dugouts propelled by engines. Both uses of chain saws and engine-powered canoes, as indicated by several loggers, should likely increased daily production and size of marketed woods and therefore loggers' revenues. As in many areas worldwide, harvesters were willing to venture widely in search of particular trees that have high local market value (Rasolofo 1997; Dahdouh-Guebas *et al.*, 2000a; Hauff *et al.*, 2006; Barbier 2007; Walters *et al.*, 2008). We found that *Rhizophora* spp. was more highly selected for this purpose.

Interestingly, our results indicate that the average monthly incomes of loggers were quite similar between age classes. This could be due to the fact that a wide range of harvesters, except older loggers who were less active, currently used both chain saws and slicers during logging activities. Furthermore, traditional boats usually have the same capacity that allows loggers to carry the same quantities of marketable wood (Fig. 2.2 A). However, small-scale mangrove cutting by older loggers is closely related to their common use of carpenter saws and machetes. The latter was different in a Venezuelan case where older mangrove users were found to be more experienced mangrove wood harvesters than younger ones (Lopez-Hoffman *et al.*, 2006).

We did not consider the impact of harvest frequency on loggers' monthly income since the wood quantity cut down was mainly influenced by the nature of logging materials (chain saw use accelerates mangrove loss more than slicers or machetes) (Table 2.4). This explains the fact that most of marketed wood diameter range from 40 cm to 60 cm. The wide range of sizes and species selectivity in cutting is closely related to the current increasing demand for commercial fuel-wood and charcoal in Douala city. Likewise, loggers' income was not significantly different between age classes (see results). This could also suggest that the wood prices in all markets investigated so far are not different. We did not make proper trend analyses of this hypothesis because of discrepancies among the form of marketed woods (*e.g.*, woods are sold in form of cubic meter or heap).

Taking into account the survey period and respondents' experience in logging activities, our results show that 87.5% of harvesters have started marketing wood during the 1990s. The high number of loggers with less than 10 years of experience in logging can be easily explained by the fact that towards the end of last century, several African countries, including Cameroon, were struck by serious socio-economic crises, which resulted in high levels of unemployment and widespread poverty (UNEP 2007). Therefore, commercial exploitation of mangrove products became an important income supplement for coastal communities that are closest to the Wouri estuary.

Considering the fact that other anthropogenic pressures (especially urbanization) provoked an irreversible degradation, the luxuriant mangrove forest of the Cameroon Estuary with its current estimated surface area of about 1,000 km^2 has < 100 years left before being entirely converted into plantings without *Rhizophora* trees (Din *et al.*, 2008; UNEP 2007; Rönnbäck *et al.*, 2007). This corresponds well with Duke's *et al.* (2007) prediction of a world without mangroves.

2.4.2 *Subsistence uses*

The use of considerable amounts of fuelwood, particularly from *Rhizophora*, as *banda* for smoking fish, rather than just for cooking or charcoal as reported in many other countries among which Kenya, India and Malaysia (Aksornkoae *et al.*, 2003; Dahdouh-Guebas *et al.*, 2000a, 2006), is unique for the Cameroon case. This important activity (fish smoking) around the Douala-Edea reserve was regarded as a local fish preservation technique.

The use of *Laguncularia racemosa* as a construction material, particularly for fences, has also been recorded in the region of the Mexican Pacific coast by Hernández Cornejo *et al.* (2005), who reported additional medicinal use of *Avicennia germinans* (*e.g.*, tea made from the leaves of *Avicennia germinans* was used for the treatment of gastric diseases) that was not found in the present study. Although the use of *Nypa fruticans* as thatching material for house walls and roofs has been reported at Mbiako, Yoyo I and Yoyo II, others non-wood mangrove uses (food, fodder, alcohol, sugar, medicine and honey) found worldwide (FAO 1994; Dahdouh-Guebas *et al.*, 2000a; Hernández Cornejo *et al.* 2005; Dahdouh-Guebas *et al.*, 2006; FAO 2007) were not mentioned here.

Because they are geographically isolated and surrounded only by mangrove forests, the villagers reported that they did not know about alternatives to mangrove wood. Therefore, high household demands for firewood and housing have greatly affected plant populations. Because villagers were not also in good position to be selective, they would harvest what was most readily available to them (Barbier & Cox 2003). This explains why mangrove ecosystem was of prime importance to most of the respondents (87%) despite the fact that it's declining.

2.5 CONCLUSION

Around the Wouri estuary and the Douala-Edea reserve, local communities often depend on mangroves for subsistence and for commercial needs. Big logs with diameter greater than 40 cm were commonly sold by loggers at the Douala wood markets. However, loggers who were also involved in informal job practices often delivered logs to various resellers. Besides mangrove wood selling, *Rhizophora racemosa* and *R. harrisonii* were commonly used for fuelwood by villagers. The socio-economic value of mangroves in our study area is real and sufficiently important to merit greater interest from different stakeholders. Therefore, small-scale programmes of mangrove reforestation and afforestation should be recorded at the local levels especially where mangroves are irreversibly degraded. Furthermore, mangrove logging should be regulated through law enforcement, less use of chain saws, awareness and alternative jobs proposal.

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PLANCHE 3. Les forêts de mangroves aux environs de Douala (Cameroun) sont habituellement déforestées pour la collecte du bois et la construction des habitations.

PLATE 3. The mangrove forests around Douala (Cameroon) are commonly clear-felled for wood collection and house building.

CHAPTER 3

ASSESSING FOREST PRODUCTS USAGE AND LOCAL RESIDENTS' PERCEPTION OF ENVIRONMENTAL CHANGES IN PERI-URBAN AND RURAL MANGROVES OF CAMEROON, CENTRAL AFRICA

ADOLPHE NFOTABONG ATHEULL[1,2*], NDONGO DIN[2], ESSOMÈ KOUM GUILLAUME LÉOPOLD[2], BEHARA SATYANARAYANA[1,3] AND FARID DAHDOUH-GUEBAS[1,3]

[1]Laboratory of Systems Ecology and Resource Management, c/o Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles – ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium.
[2]The University of Douala, Faculty of Science, Department of Botany, Douala, Cameroon.
[3]Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussel - VUB, Pleinlaan 2, B-1050 Brussels - VUB, Belgium.
*Corresponding author

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ABSTRACT

Deforestation is one of the most ubiquitous forms of land degradation worldwide. Although remote sensing and aerial photographs can supply valuable information on those environmental changes, they may not be available in some tropical coastal regions (*e.g.* Cameroon estuary) where cloud cover is frequent. With respect to mangroves, researchers are now employing local knowledge as an alternative means of understanding forest disturbances. This paper was primarily aimed at assessing the mangrove forest products usage, along with the local's perceptions on environmental changes, between the Littoral (Cameroon estuary) and Southern (mouth of the Nyong River and Mpalla village) (regions) of Cameroon. The data from both locations were obtained through conducting household interviews and field observations. Significantly more respondents than expected used mangrove species for fuelwood (*Rhizophora* spp.) and housing (*Rhizophora* spp., *A. germinans* and *N. fruticans*) in the Cameroon estuary compared to what was recorded in the mouth of the Nyong River and Mpalla village. Although local people perceived wood extraction as a greater disruptive factor, it is a complex mix of causes that have led to changes in the mangrove of Cameroon estuary. Factors identified as causing mangrove damage, but not observed in the Southern region, include over-harvesting, clear-felled corridors, sand extraction and housing. Findings from this study highlight the need to improve sustainable management of these coastal ecosystems through afforestation (in large impacted areas), selective removal of senescent trees stems and branches (in little damage stands), limitation of sand extraction and housing, awareness and law enforcement.

Keywords: Local knowledge; non-timber forest products; over-harvesting; sand extraction; housing; anthropogenic disturbance; mangroves; Cameroon

3.1 INTRODUCTION

Deforestation is a major environmental concern that societies around the world are currently facing (Ehrlich & Mooney 1983; Houghton 1994; Dobson *et al*., 1997; Kovacs 2000). One of the most obvious cases is found along the tropical and subtropical coastlines. Here, mangroves are disappearing at a rate greater than or equal to decline in adjacent terra-firme rain forests (Valiela *et al*., 2001). The causes of losses have been mainly attributed to anthropogenic activities (Hernández-Cornejo *et al*., 2005; FAO 2007; Walters *et al*., 2008). Mangrove wood products remain an important source of building and fuelwood material for local communities (Bandaranayake 1998; Dahdouh-Guebas *et al*., 2000a; Walters 2005a; UNEP 2007; Nfotabong Atheull *et al*., 2009). Therefore, in order to ensure that future generations enjoy the ecosystem services provided by such valuable natural ecosystems (Duke *et al*., 2007), it is fundamental to assess the environmental changes that occurred in the mangrove ecosystems.

Though remote sensing and aerial photographs can supply valuable long-term data on forest cover changes, they are not always available in some parts of the tropics (*e.g.* Cameroon coast in Central Africa) where cloud free images are rare. With a scarcity of such datasets in the developing countries, several researchers are now employing local knowledge as an alternative means of reconstructing changes in the mangrove forests (Kovacs 1999, 2000; Kovacs *et al*., 2004; Dahdouh-Guebas & Koedam 2008). The consistency of this alternative approach is related to the fact that local inhabitants can provide insight into certain environmental changes which may be missed by exact sciences alone (Rochet *et al*., 2008; Schaich 2009; Agho *et al*., 2010). Hence, an understanding of how people perceive the long term changes within mangrove is of great importance (Crona *et al*., 2009; Conchedda *et al*., 2011).

In this study, we surveyed residents of the Littoral and Southern part of Cameroon on their wood product utilization and perception of mangrove changes. The aims were: (a) to confront the usages of mangrove wood products in the Southern Cameroon (close to the mouth of the Nyong River) and Mpalla village (Kribi) in comparison with the Littoral region (Cameroon estuary); and (b) to compare the local residents' perceptions on environmental changes that occurred within the two mangrove forests.

3.2 MATERIAL AND METHODS

3.2.1 *Study area*

Mangroves in the mouth of the Nyong River (3° 15' N and 9° 55' E) and Mpalla village (2°59'N and 9°55'E) are bordered by a boundless terrestrial evergreen forest (Fig. 3.1).

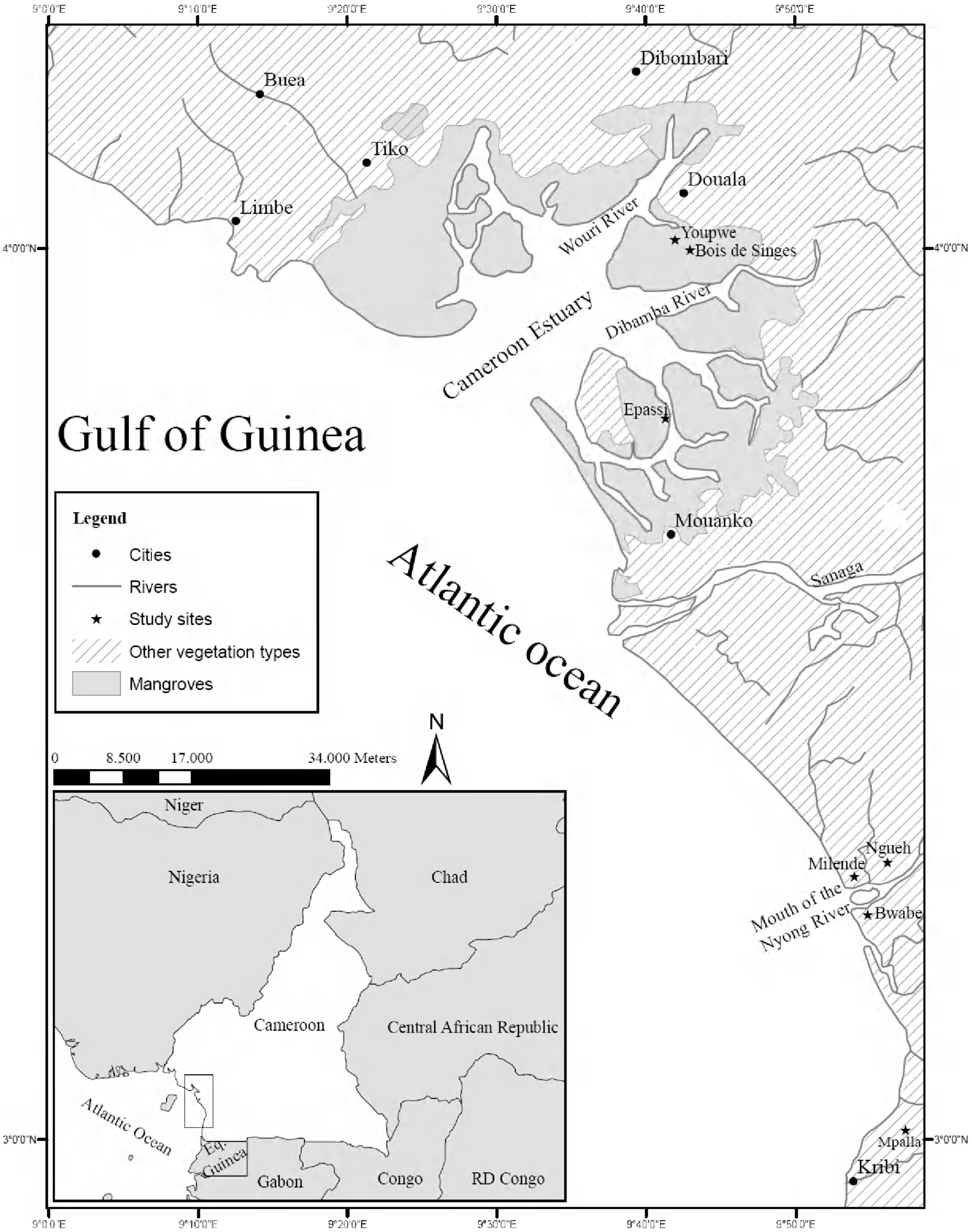

FIG. 3.1 Map showing study area and the seven selected mangrove sites.

These coastal ecosystems annually receive about 2870 mm of precipitation. The Cameroon estuary (3°53’N and 9°38’E), with its two irregular seasons and a mean annual rainfall of 3988 mm, shares more than 30% of its continental limit with Douala, the first most populated city in Cameroon (Din *et al.*, 2008). The Littoral and Southern regions are also distinguishable in terms of mangrove area (small patches in the mouth of the Nyong River and Mpalla village and large units in the Cameroon estuary) and anthropogenic pressure (rural in Nyong and Mpalla village and peri-urban in the Cameroon estuary), and therefore makes this study highly relevant for appropriate conservation and management purposes.

3.2.2 *Data collection*

The data were generated through conducting semi-structured interviews with local residents (mostly fishermen living in the immediate vicinity of the mangroves) and our field based observations. Between 15 December 2007 and 25 February 2008, a semi-structural questionnaire (based on Dahdouh-Guebas *et al.*, 2000a, 2006) was used to investigate the two peripheral quarters of Douala (*i.e.*, Youpwe and Bois de Singes), two large villages (Epassi and Mpalla) and three small neighbouring villages (Milende, Ngueh and Bwabe) (Fig. 3.1). Most interviews were done in French, except in Mpalla and Bwabe, where a local language (*Batanga)* was used with the help of a translator.

Household visits were carried out at the end of the fishing activities. The households were sampled opportunistically (respondents encountered in their houses were interviewed). Nine homes were hostile to our visit and five people refused to answer. Nevertheless, a total of 120 accepted to participate. To avoid recurrent information, only one person (> 20 years of age) per house was questioned. The preference was given to (local) elderly people who were living in the site for more than a generation and therefore could relate changes that have been occurred in adjacent mangroves to certain events or conditions. Interviewees were asked if the surrounding mangrove forest had increased, decreased or remained unchanged in cover. Likewise, an attempt was made to distinguish whether local informants perceived mangrove forests as less or more degraded over time. They were urged to provide the causes of the reported changes and the derived consequences on their livelihood. Local peoples were also asked questions about any observed changes in the mangrove ecosystem.

A catalogue showing mangrove plants and their physiognomy, leaves, fruits and flowers was used (as described in Dahdouh-Guebas *et al.*, 2000a, 2006) to assess the level of each respondent's knowledge on the mangrove species available locally. However, local informants were unable to distinguish the characteristic differences between *Rhizophora racemosa* Meyer, *R. harrisonii* Leechman and *R. mangle* L. (classification based on Tomlinson 1986) whenever pictures of their leaves, fruits or flowers were presented to them. Although *R. racemosa* is the dominant species in Cameroon mangrove forests (*cf.* Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009), the genus name was adopted when the use of one of the above three species was reported by the respondents.

Data on local people's demography (*e.g.*, age, gender, etc), along with plant vernacular names and their parts used for timber and non-timber forest products including ethnopharmacological (*i.e.*, human diseases treated, methods of remedy preparation and administration) and chemical usages (*e.g.*, dye preparation), were gathered during the household interviews.

3.2.3 *Data analysis*

Amongst 120 questionnaires filled, 110 (60 in the Cameroon estuary and 50 at the mouth of the Nyong River and Mpalla village) were used for statistical analysis and 10 were discarded because of incoherent information. Chi-square test (χ^2) (SPSS *v.* 16.0) was used: (a) to determine if there was any significant difference ($p < 0.05$) in mangrove use by region, and (b) to confront the level of degradation reported by informants in the Littoral (region) with that of the Southern (region). Principal component analysis (PCA) was performed with PRIMER *v.*6 to assess which patterns of use were perceived as factors largely contributing to the mangrove degradation in each sample site. It is important to highlight that the answers from the ethnobotanic (traditional species usage) section of the questionnaire reported by those people who could not distinguish at least one species were not taken into account for further analysis, although their general perceptions on environmental changes were considered.

3.3 RESULTS

3.3.1 *Local people knowledge on mangroves*

The majority of informants were males and their age range was between 21 and 72 years old. (45.09 ± 12.16; mean ± 1SD). In both parts, respondents referred to the mangrove forest as *matanda* and when asked to identify *Rhizophora* tree, many of them referred it as *itanda* (Table 3.1).

In the Cameroon estuary, 69.23% of respondents (mostly elderly peoples) could distinguish two to four mangrove plants, whereas the informants (65.45%) in the mouth of the Nyong River and the Mpalla village (mostly youngster peoples) are familiar with only one to two commonly found mangroves there (*e.g. Rhizophora* spp. and *Avicennia germinans* (L.) Stearn.

Table 3.1 Subsistence uses of mangrove woods in littoral and south Cameroon

Mangrove taxa	Local name (*batanga, Duala)*	Part used	Uses
Rhizophora spp.	*itanda,*	stems	commercial firewood and charcoal, precarious house construction (poles), plank-making, flagstone support, fabrication of tables, chairs, boats/canoes immobilisation.
		branch	domestic firewood, fencing.
		bark	malaria treatment (external usages), stop ping of external haemorrhages, stomach illness (ingurgitation), tooth decay treatment, tainted fishing net.
		root	fabrication of shuttle.
Avicennia germinans	none reported	stems	commercial planks for construction, paddles, traditional boat/canoe construction, bench, chairs.
		branch	domestic firewood.
		leaves, bark	malaria treatment (external usages), smelly/stinky body.
Laguncularia racemosa	none reported	stems	Boat/canoe construction, paddles, firewood (household consumption).
		leaves, bark	treatment of measles, gonorrhoea, malaria, stomach illness.
Nypa fruticans	*Lende la djengu*	leaves, fruits	mat confection, wall dressings. house roofs decoration.

3.3.2 *Utilization of mangrove resources*

During the field observation, a total number of five mangrove species namely, *R. racemosa, R. harrisonii*, *A. germinans*, *Laguncularia racemosa* (L.) Gaertn. f. and *Nypa fruticans* (Thumb.) Wurmb., were recorded in the Littoral part of Cameroon. The same number of species (*R. racemosa*, *R. mangle*, *N. fruticans, A. germinans* and *L. racemosa*) were observed in the Southern part.

In Cameroon, the mangrove products are locally utilized as fuelwood (*e.g.* charcoal making, cooking or heating of the traditional henhouses), construction materials, service wood, dye or medicine (Table 3.1). Within the Littoral region, the use of mangroves for fuelwood (Fig. 3.2 A), construction materials (Fig. 3.2 B) or service wood (Fig. 3.2 C, D) in Epassi are almost similar to that of Youpwe ($\chi^2 = 0.82$; d.f. = 2; $p > 0.05$).

With regard to the three aforesaid uses, mangrove wood collection is not statistically different in Bois de Singes compared to Youpwe ($\chi^2 = 5.18$; d.f. = 2; $p > 0.05$). However, significantly fewer residents use mangrove either as fuelwood, construction materials or service wood in Bois de Singes compared to Epassi ($\chi^2 = 6.87$; d.f. = 2; $p < 0.01$) (Table 3.2). In the Southern region, mangrove harvesting for the same purposes did not differ much between Mpalla and the mouth of the Nyong River (Milende, Ngueh and Bwabe) ($\chi^2 = 0.97$; d.f. = 2; $p > 0.05$).

FIG. 3.2 Photographs illustrating different mangrove uses in mangroves of Cameroon: (A) Mangrove poles obtained from *Rhizophora* spp are used for fish smoking ready to sell in the local market (Youpwe). (B) Use of *Rhizophora* small timber for precarious house building at Youpwe. (C) *N. fruticans* leaves used for walls covering at Epassi. (D) "Shuttle" crafted from *Rhizophora* prop roots at Mpalla village (Kribi).

Collection of mangrove for the above recorded purposes was most important in the Cameroon estuary than was the case in the mouth of the Nyong River and Mpalla village (χ^2 = 6.75; d.f. = 2; $p < 0.05$) (Table 3.2). *Rhizophora* timber was used for the establishment of houses, especially in the Cameroon estuary (Table 3.1). The choice here for making those houses with small *Rhizophora* trees was based on its aesthetic, availability, easy to harvest and rot-resistant characteristics (Fig. 3.2 B). The wall dressings and planks were obtained from *Rhizophora* spp. and *A. germinans* trunks. *N. fruticans* leaves were also used for wall dressings. In order to reduce the entry of air currents inside the precarious houses (in Epassi village), the walls were first covered by plastic sheets and then by *N. fruticans* leaves on the top (Fig. 3.2 B, C). *Rhizophora* trunks constituted an important component of traditional chairs, benches and tables just like *A. germinans* stems, which were also used for canoe construction and paddle fabrication. The latter two wood products could also be obtained from *L. racemosa* trunks.

Table 3.2 Mangrove wood products used in different sites. Comparisons in mangrove uses for fuelwood, house construction and service wood are made within and between the two regional sites. Areas showing significant difference in mangrove uses are highlighted with similar colors. Values represent the number of respondents indicating that they use mangrove plants (N = 110 respondents).

	Sites	# Questionnaires	Mangrove uses				
			Fuelwood	Construction	Service wood	Medicinal	Chemical
LITTORAL REGION	Cameroon estuary						
	Youpwe	20	16	10	6	0	0
	Bois de Singes	16	6*	0*	0*	0	0
	Epassi	24	24	16	15	3	3
	Total	**60**	**46***	**26***	**21***	**3**	**3**
SOUTHERN REGION	Mouth of Nyong River						
	Milende	12	6	1	3	3	1
	Ngueh	6	0	0	2	1	0
	Bwabe	7	2	1	0	4	0
	Kribi						
	Mpalla	25	8	2	10	0	3
	Total	**50**	**16**	**4**	**15**	**8**	**4**

* $p < 0.05$.

There were no significant trends between the two regions in mangrove usage for medicine and for dye for clothes or nets ($\chi^2 = 0.46$; d.f. = 1; $p > 0.05$) (Table 3.2). Medicinal products from mangrove plants were only used in wedged zones like Epassi, Milende, Bwabe and Ngueh. Their collection and transformation into medicinal products were done in general by women. *A. germinans* leaves and bark were used to treat malaria patients. The bowl or pot with boiled water and *A. germinans* leaves and barks, together with the sick person, were covered with a thick blanket for inhaling and then swallowed. The same technique was also used to cure measles and gonorrhoea with the leaves and bark of *L. racemosa*. According to local people, high perspiration could even eliminate bad odour from the patient's body. The decoction after boiling *Rhizophora* bark was used to stop external haemorrhages and to cure tooth decay. Chemical usages were particularly reported at Mpalla, Epassi and Milende where the liquid obtained from fresh *Rhizophora* bark was used to dye and preserve faded clothes and cotton fishing nets, the latter was reported to attract more fish.

An essential tool that made from *Rhizophora* prop roots for weaving fishing nets was called "shuttle", and it was crafted by artisans who were not always fishermen (Fig. 3.2 D). The preference with *Rhizophora* prop roots was because of its strength and durability. The shuttle's central part, which was empty except for a thin axis, was used to spin around fishing thread, and the entire tool was then used with the concave extremity to weave the fishing net. These shuttles were also available in the local market at Mpalla village with a price ranging from 0.30 to 0.45 € (0.35 ± 0.05 €) (the exchange rate at the time of data collection was 1 € = 655.95 FCFA).

3.3.3 *Environmental changes in mangroves*

3.3.3.1 Perceived changes to mangrove stands

According to local people, the mangrove forests in Mpalla (Kribi) and in the mouth of Nyong River were not as severely degraded as those in the Cameroon estuary ($\chi^2 = 67.94$; d.f. = 2; $p < 0.001$) (Table 3.3). Here, more than half (66.15%) of the interviewees reported considerable damage of mangroves (Table 3.3). On one hand, they recounted that there was a loss of mangroves in some areas. On the other hand, they stated that the remaining stands were commonly degraded. About a third (32.31%) of residents' support that the mangrove was not threatened and accordingly has remained the same, whereas a tiny minority (1.54%) perceived mangrove to be only slightly degraded.

Table 3.3 Local residents' perception of changes occurred in mangroves (N = 120 respondents).

Sites	Number of respondents	Reported level of degradation		
		No change	Little	Large
Cameroon estuary	65	21 (32.31%)	1 (1.54%)	43** (66.15%)
Mouth of Nyong River and Mpalla village	55	23 (41.82%)	31 (56.36%)	1 (1.82%)

** $p < 0.001$. Values in parentheses indicate percentage of the respondents per type of perception per site.

In the Cameroon estuary, several informants perceived mangrove wood extraction, as a major disruptive factor. They overwhelmingly acknowledged that prior to the construction of their houses, the areas were covered by mangrove forests. An important part of these participants ranked housing activities as a second threat. Though all respondents generally agreed with the ecological importance of mangrove (*i.e.*, coastal stabilization), they declared that this ecosystem was the only area where they could freely clear for housing. Beside this assertion, other residents reported that the daily dumping of untreated domestic wastes could also be considered as a factor contributing to mangrove degradation. However, significant evidence signs of forest degradation were not observed in and around the concerned areas by the authors. Respondents had an opinion of less potential damage to mangroves with sand extraction (Fig. 3.3 A) since the people disturb only substratum. It is also important to highlight that the areas (up to a distance of 3 km) reported with municipal and domestic pollution are free from sand extraction activities.

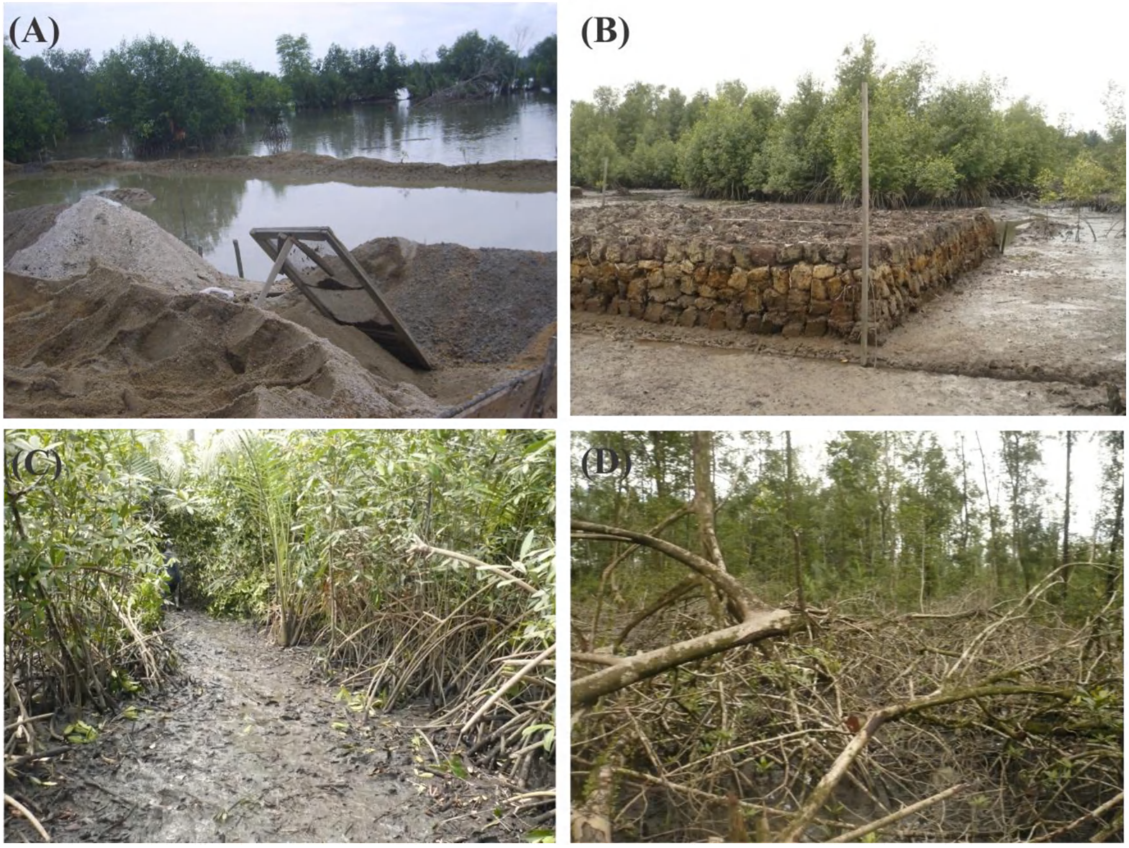

FIG. 3.3 Mangrove land degradation in Cameroon. (A) Sand extraction within mangrove forest. The background shows uncut sparse adults trees. (B) Elevated areas of previously cleared mangrove stands waiting for housing. (C) Clear-felled corridor within the mangrove used for wood transport or as access path. (D) Complex of cut branches and prop roots (*Rhizophora* spp.) left in situ.

In the mouth of the Nyong River and the Mpalla village, about 56.36% of respondents indicated that the existing mangrove was less impacted (Table 3.3). While fewer Mpalla residents' explained that the fringe mangrove which formerly bordered the sea edge has been entirely cleared by the foreign residents for land development projects, more than one-third (41.82%) of the Southern informants' argued that the mangrove was less disturbed. Some residents of the latter category admitted that they slightly cut mangrove trees growing in the immediate vicinity of their houses. In contrast, several fishermen in Mpalla village indicated that they were no longer able to access some of their old fishing grounds due to extensive growth of *Rhizophora* spp. prop roots and mud deposition along the channels obstructing their boat passage. Indeed, people of this region clearly stated that they often preferred non-mangrove species (*e.g.*, *Lophira alata* C.F. Gaertn. locally called *bojambi* or *azobé*) with nearly the same calorific value as *Rhizophora* spp.

Beside the residents' statements, the other non-reported, but field-observed anthropogenic activities (*e.g.* digging, landfill, dyke construction, large clear-felling) would also greatly contribute for land degradation. Mangrove trees were completely uprooted, the consolidate sediment dug, manually transported and packed in a previously cleared mangrove stand

(Fig. 3.3 B). Interviewees claimed that this kind of elevated area was most suitable for housing as it could also prevent the daily tidal inundation. In general, the large impacts observed in mangrove stands could not bring the vegetation back to a healthier state again.

Another notable anthropogenic factor observed in Youpwe and Epassi, but not stated by informants, was the clear-felling of young mangrove trees (in 1.5 m width as a corridor) from the cutting place to the water channel(s) where they anchor boats (Fig. 3.3 C). In order to facilitate wood transportation, big logs were progressively pushed on mud along the clear-felled corridors in the mangrove areas. These corridors are also used as path later on by several loggers. This phenomenon constituted a serious disturbance in this ecosystem since it prevented mangroves to naturally recover from the previous impacts. Unlike large stems of *Rhizophora* which were cut, split and transported mostly for commercial purposes, their branches and stumps (with under-ground roots) were usually left in the field (Fig. 3.3 D).

The PCA performed on the perceived causes of mangrove degradation in each sample site is shown in Fig. 3.4. The first PCA axis explained 71.30% (*i.e.*, eigenvalue of 7.03) of the total variability whereas the second one represents 26.30% *(i.e.*, eigenvalue of 2.59) of the total variance. The two other PCA axes were of low interest as none of the relating eigenvalues was above 1. The linear coefficient of original variables (perceived causes of mangrove damage) making up PCA's revealed that the respondents in Epassi saw logging and housing as the main sources of mangrove degradation (Fig. 3.4). These two patterns of uses clustered along the negative and positive parts of the PCA1 and PCA2, respectively. In contrast, Bois de Singes was mostly characterized by a perception of mangrove damages from municipal/domestic sewage pollution and sand extraction. Both anthropogenic activities clustered along the lower parts of first and second principal component (Fig. 3.4). Regarding the Youpwe site, informants perceived mangrove degradation as a consequence of housing and sand extraction. The Southern villages were all characterized by few concerns degradation in mangroves, and accordingly clustered along the upper parts of the two first principal components.

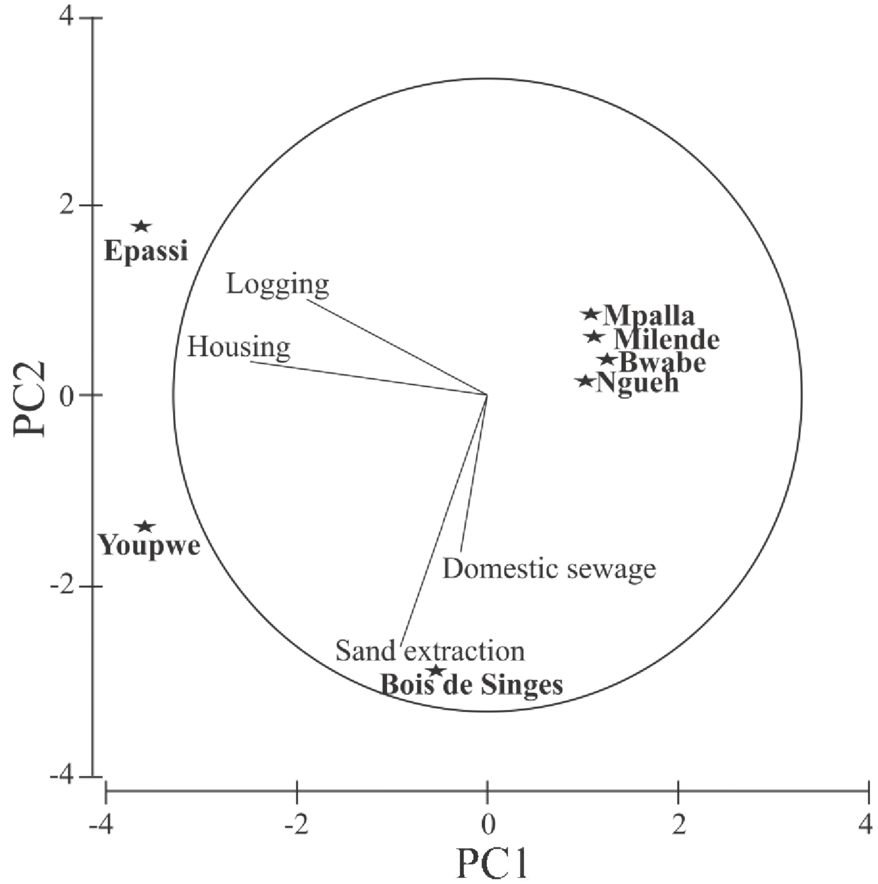

FIG. 3.4 Principal Component Analysis of the perceived causes of mangrove degradation across the study area. It could be observed that each sample site in the Cameroon estuary (*i.e.*, Epassi, Youpwe and Bois de Singes) is located close to its major degradation threats perceived. Nevertheless the four sites on the top right corner (Mpalla, Milende, Bwabe and Ngueh) are seen less influenced by those four recognized mangrove threatening factors. Each star indicates the position of its respective sampling site in the PCA plane with reference to the perceived causes of mangrove degradation. The length of each vector line represents the importance of that particular variable's contribution to the PCA axis. The circle represents the graphical illustration of the correlation between the variables and the principal components. (This analysis does not take-into account the data obtained from field).

3.3.3.2 Perceived changes in fauna composition of mangroves

Although there were few logging activities in the mouth of the Nyong River, local people unanimously shared the opinion that trawler activities near the shore have led to the decline in local fish catch inside the mangroves. This negative change was reinforced by the increased number of local fishermen. A decrease in the population of silurid, tilapia, mullets, shrimp, oyster, bivalve and crab species, as stated by informants in the Mpalla village, was probably related to changes (*e.g.*, siltation, reduced water circulation, etc) that occurred in the waterways. Though such decrease in mangrove fauna composition was also recorded in the Littoral region, many interviewees linked the reported reduction to anthropogenic disturbances (*e.g.* harvesting, clear-felling, domestic sewage, pollution and sand extraction).

3.4 DISCUSSION

3.4.1 *Mangrove plant uses*

Almost in every tropical and sub-tropical regions of the world, mangrove forests are widely harvested for different purposesv (Dahdouh-Guebas *et al*., 2000a; Hernández-Cornejo *et al*., 2005; Walters 2005a; FAO 2007; Din *et al*., 2008; Walters *et al*., 2008; Nfotabong Atheull *et al*., 2009). In the Cameroon coastal regions, we found that stems obtained from *Rhizophora* spp. and *A. germinans* are commercially important whereas their branches, in a few cases, were preferred for domestic utilization. Studies have documented that different mangrove species have different wood properties, making some more suitable than others for specific uses (Walters *et al*., 2008). The stems of *Rhizophora*, characterized by hard nature and rich tannins, were perceived to be highly marketable goods for their potential use as firewood, charcoal and construction materials (Bandaranayake 1998). This wood is less appropriated for plank-making than that of *A. germinans*, the latter being easiest to split. Except in Epassi village (located 25 km away from Douala city), none of these two species were used for *banda* construction (a table-like structure made from mangrove timber to smoke fish) as previously recorded by Nfotabong Atheull *et al*. (2009) in the Douala-Edea reserve. However, instead of *banda*, the locals in Youpwe are using hollow iron drums (with its upper surface cover by *Rhizophora* branches) for fish smoking. The advantage with this kind of oven is said to be for keeping the smoked fish warm for longer durations.

Although there were no reports on the use of *Rhizophora* prop roots for “shuttle” fabrication in the Littoral region, it is an activity carried out by some fishermen in Mpalla village. The strength and durability of the “shuttle” reduced the frequency of prop roots harvesting (about two prop roots per adult tree are cut) and tree felling. In addition, some artisans stated that their frequency of visits to the mangrove was limited because of the harsh environment. While both leaves and bark of *A. germinans* and *L. racemosa* are used in ethnopharmaceutical purposes, only the bark of *Rhizophora* is served for medicine and chemical purposes (Table 3.1). Similar uses of *A. germinans*, *L. racemosa* and *Rhizophora* have been reported by Kovacs (1999) and Hernández-Cornejo *et al*. (2005). The bark of the above species is an excellent remedy for curing several diseases (malaria, measles and gonorrhoea) because of its rich soluble tannins (Walsh 1977) which may inhibit microbial activity (Wooller *et al*., 2003). Similar chemical usage (for dye preparation) of the barks obtained from *Rhizophora* and *Ceriops decandra* (Griff.) Ding Hou was also reported from Coringa mangroves in the Godavari Delta, India (Dahdouh-Guebas *et al*., 2006).

3.4.2 *Perceived environmental changes in mangroves*

Local knowledge can contribute to the identification and evaluation of factors inducing environmental disturbances in mangrove forests (Kovacs 2000; Walters 2005b). The perceived degree of mangrove damages differs between the Littoral and Southern parts of the Cameroon coastlines.

3.4.2.1 Mangrove changes in the Littoral region

In the case of Cameroon estuary, the high rate of unemployment coupled with lax government enforcement and the peri-urban situation of mangroves favour the large degradation of forests (Fig. 3.5). Here, while local loggers are waiting for a formal job, they often cut mangrove wood for commercial utilization (Nfotabong Atheull *et al.*, 2009). As mentioned in the result part, the majority of local people perceived that wood harvesting and house construction are significant causes of mangrove damages. Instead of focusing on both causative factors, it is always worth to highlight the combination of issues which are truly responsible for changes in the mangrove forests (Fig. 3.5).

Another possible cause for extensive mangrove degradation in the Cameroon estuary could be the high rate of population growth, which can uplift the anthropogenic pressure on adjacent ecosystems (Din & Ngollo 2002; Din *et al.*, 2008; Feka & Manzano 2008). This threat is of great concern since a considerable proportion of informants living in the Littoral region stated that they can liberally used mangrove areas for housing.

Residents greatly recognized that some mangrove stands are nowadays occupied by houses. They furthermore explained that to avoid difficulties, house construction often starts with dyke enclosures (to reduce water supply), then mud cracking and finally tree clear-felling. With regard to these statements and the findings of Din & Blasco (1998), anarchic urbanization constitutes an additional significant threat contributing to the mangrove degradation in the Cameroon estuary (Fig. 3.5). The extent of subsequent damage depends on the intensity, persistence and periodicity of forest disturbance (Hauff *et al.*, 2006; Ambastha *et al.*, 2010), as well as the type of anthropogenic activity carried out. Likewise, cutting could also lead to a dramatic effect from which recovery may be slow or even impossible (Kovacs 1999; Walters 2005b; Hauff *et al.*, 2006; UNEP 2007; Walters *et al.*, 2008). The speed of recovery is function of the forest type affected and the density of seedlings and established propagules prior to cutting. For instance, in disturbed *Rhizophora* zone, cut branches and prop roots left in the site, often trap mangrove propagules and prevent their dispersal into the inner disturbed zones. However, this phenomenon is less within the disturbed monospecific stands of *A. germinans* where its seed retention by cut branches and pencil roots is limited.

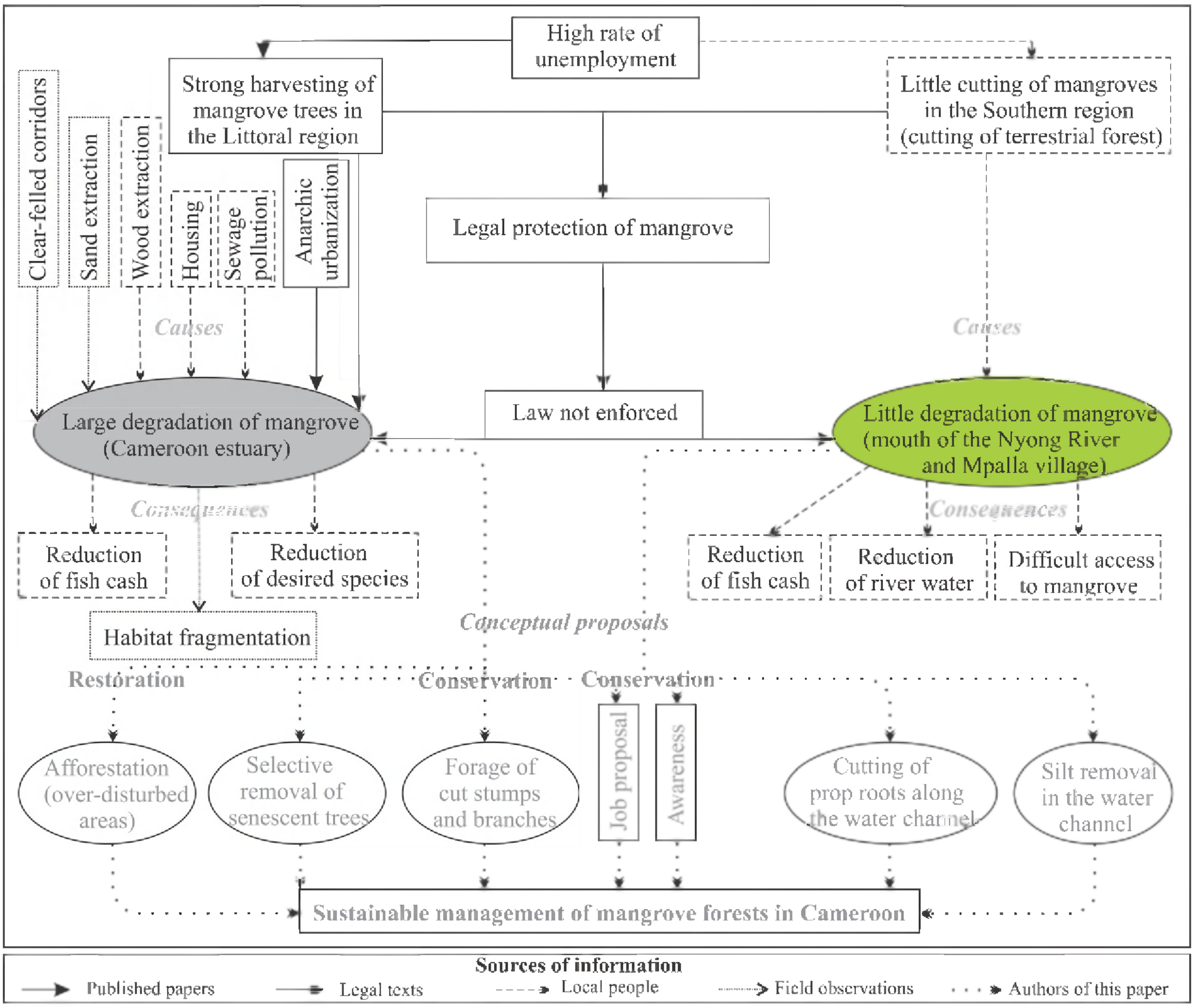

FIG. 3.5 Flowchart showing the causes of mangrove degradation as well as remedies (conceptual proposals) for its proper conservation and management strategies in Cameroon. Each source of information is represented by different type of arrows. The causes as well as consequences of large (Littoral region) or little (Southern region) degradation of mangrove forests are also differentiated.

In contrary to informants, the impact of untreated anthropogenic sewage pollution on mangroves cannot be proved with the current observations. In addition, some studies have indicated enhanced mangrove (Boonsong *et al.*, 2003; Mohamed *et al.*, 2009) and shrimp (Penha-Lopes *et al.*, 2011) growth, with no apparent negative effects (Wong *et al.*, 1997; Vaiphasa *et al.*, 2007; Crona *et al.*, 2009), after releasing the synthetic wastes into mangroves. The mangrove vegetation in that area (Bois de Singes) seemed to confirm that assertion.

A detailed analysis of the PCA has already showed that the perceived causes of mangrove damages differ across the sample sites. In the Cameroon estuary, the site separation is probably due to the relatively higher heterogeneity amongst the sample sites with respect to some patterns of use. As example, Bois de Singes was the only concerned about municipal/domestic sewage pollution. Such kind of pollution is common in mangrove of East Africa (Crona *et al.*, 2009). Residents of the aforesaid site like those of Youpwe also qualified sand extraction as a threat to mangrove. But, Youpwe residents' attributed similar threat potential to sand extraction and housing. Likewise, sand extraction and housing were rated almost equitably in Epassi. Therefore, the discrepancies amongst sites likely denote the differences in site locations. For instance, in a non-urban site like Epassi, sand extraction and municipal/domestic sewage pollution are unknown activities and accordingly weighted more the perceived negative effects of logging and housing. However, in the peri-urban site such as Youpwe, the diverse perceived threats could explain the intermediate position of this site. Based on our field observations, clear-felled corridors in the mangrove areas, sand extraction, urban expansion and housing and associated activities (dyke construction, large clear-felling and digging) could be seen as the major threats creating almost irreversible changes in the species composition and distribution. Of course, it is clear from the results that clear-felled corridors could lead to the fragmentation of mangrove habitats in Youpwe and Epassi. Moreover, in some mangrove stands at Bois de Singes, the destruction of propagules by sand extraction might prevent natural regeneration, which could be masked by the continued presence of patched trees (see Fig. 3.3 A). This was similar to what Lewis III (2005) observed and quoted it as 'propagules limitation'. Notice that the concerns are not restricting to the propagules alone since residents in the Littoral region recognized a reduction of fish cash as well as the desired species and related this negative change to the anthropogenic disturbances.

3.4.2.2 Mangrove changes in the Southern region

Like in the Littoral region, there is also a high rate of un-employment and none enforcement of the law protecting mangrove in the Southern part. Yet, mangroves in the mouth of Nyong River and Mpalla village were seen to be only slightly degraded (Fig. 3.5). This is clearly illustrated in the PCA by a grouping of sites sampled in the Southern region. The low perceived threat to the mangrove might be due to a less dependency of residents to this intertidal forest. In fact, the Mpalla and other villages in the mouth of the Nyong River are surrounded by terrestrial rain forest on which the local people mostly depend for their timber and non-timber forest products (Fig. 3.5).

In the locations where there is an abundant supply of hardwood timber from other forest types (*e.g.*, Australia), the use of mangrove wood has been very limited and several mangrove forests remain well conserved (FAO 2007). In the Mpalla village, this kind of situation has led to the rapid growth of *Rhizophora* prop roots and siltation (reducing the width and depth of water channels), and ultimately less access to some traditional fishing areas. This is in strong opposition with the mangrove of Nziou (Kribi located, 3 km from Mpalla) which has been deforested for land development projects (pers. obs.). However, the reported changes in Mpalla village also have a natural meaning, as it is the only water channel carrying seawater into the mangrove (the small creek mouth) and narrowing down gradually. Interestingly, the fishermen have also learned to manage with this phenomenon. Indeed, they dammed up the small creek mouth in November (beginning of dry season) and, later on, open the closure in December (mid dry season) to catch the fish that were seeking refuge or that have been trapped in the mangrove and trying to migrate back to the ocean.

3.4.3 *Mangrove restoration and conservation*

Overall, the local communities are aware of changes that occurred in their adjacent mangrove forests and most of them were willing to abandon mangrove cutting provided they find alternative jobs. For the Cameroon estuary, the restoration or rehabilitation may be considered on a priority basis only when mangrove forests have been cut to such an extent that it could no longer self-correct or self-renew (*cf.* Bosire *et al.*, 2008). Under such conditions, an afforestation policy for the mangrove ecosystem involving its reproduction and growth could be undertaken (Din *et al.*, 2002a). In this case, reforestation projects should take into consideration soil characteristics (*cf.* Kaly *et al.*, 1997) and seedling availability. However, in the zones under less harvest pressure, efforts should only emphasize on selective removal of senescent trees stems and branches, natural regeneration and awareness of local residents on the importance of mangrove ecosystem (Fig. 3.5). Local people should forage for stumps and cut branches previously left in the field and thereby reduce levels of cutting and propagule retention. Considering the fact that changes in hydrology could impact mangroves at some distance, causing the gradual die-back of particular species or entire stands (Dahdouh-Guebas *et al.*, 2005b), expanded *Rhizophora* prop roots and accumulated mud in the waterways at Mpalla (Southern region) should be regulated through selective cutting and digging processes (for silt removal in the channel).

3.5 CONCLUSION

This survey provided details on the importance of Cameroon mangrove forests in local livelihoods, along with the local's perceptions on environmental changes that have occurred in these coastal ecosystems. The large and little damage to existing mangrove stands in the Littoral and Southern region of Cameroon were clearly identified through both questionnaire and field based observations. It is a complex mix of causes (*i.e.* over-harvesting, housing, clear-felled corridors and sand extraction) that have led to environmental changes in the mangroves of Cameroon estuary. In contrast, the little damage of mangrove forests around the mouth of Nyong River and Mpalla village (Kribi) is due to a little demographic pressure and the proximity with the terrestrial evergreen forest from which the local people collect wood for their daily subsistence needs. Although the two aforesaid mangrove stands are rather less damaged, there is however an urgent need to regulate the anthropogenic pressure in the Cameroon estuary. The development of management strategies should also take into consideration ecological and economic significance of mangrove products (Walters 2005b). The enforcement of laws that protect mangrove ecosystems, combined with high awareness and alternative job proposals, are determinant for conservation of these coastal habitats.

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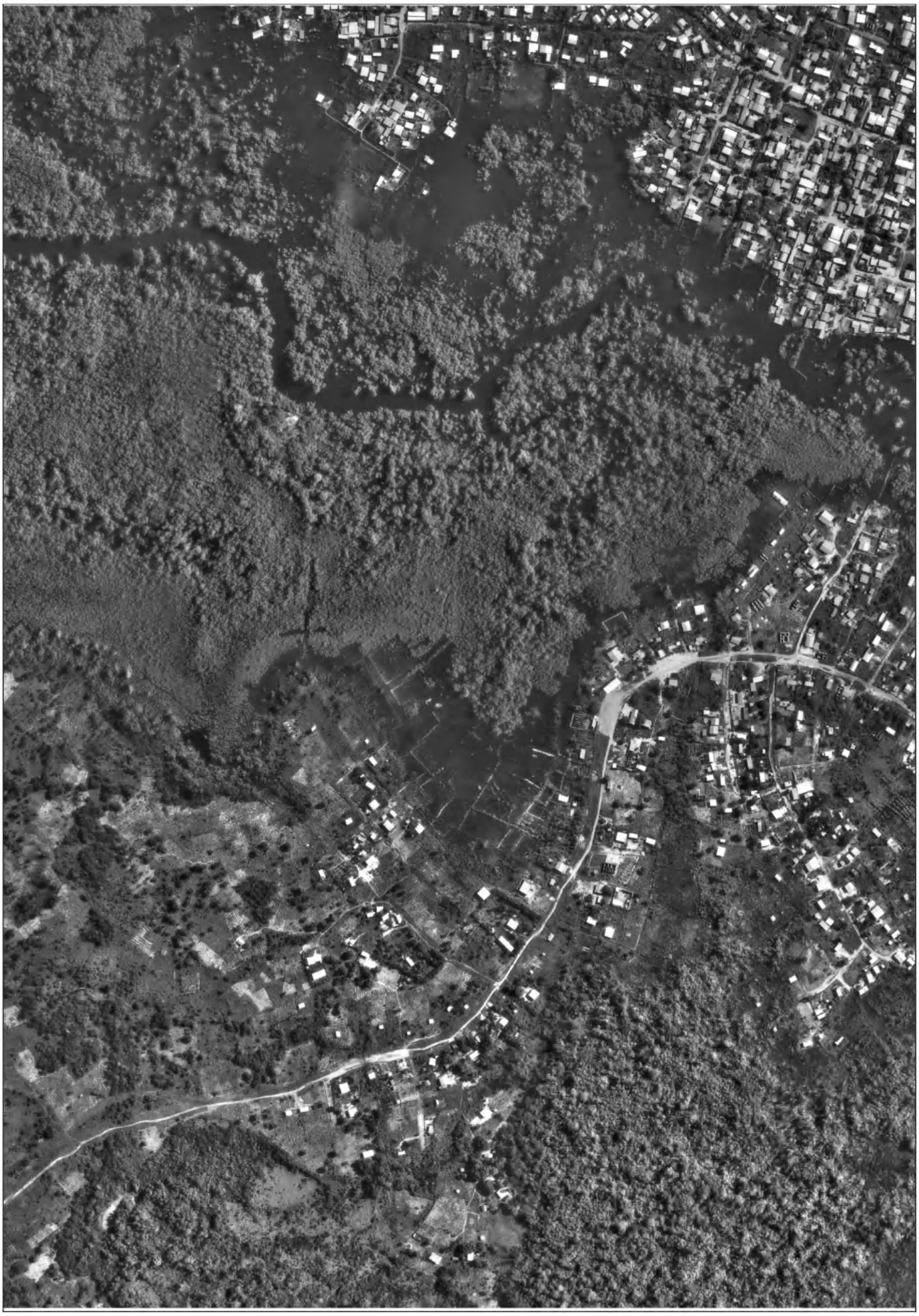

PLANCHE 4. Photographie aérienne illustrant les perturbations induites par l'homme dans les forêts de mangroves aux environs de Douala (Cameroun). Cette photo a été acquise en 2003 auprès de la Communauté Urbaine de Douala.

PLATE 4. Aerial photograph illustrating the human-induced disturbances in mangrove forests around Douala (Cameroon). This photograph was acquired in 2003 by the Douala Urban Council.

CHAPTER 4

QUALITATIVE AND QUANTITATIVE CHARACTERIZATION OF MANGROVE VEGETATION STRUCTURE AND DYNAMICS IN A PERI-URBAN SETTING OF DOUALA (CAMEROON): AN APPROACH USING AIR-BORNE IMAGERY

ADOLPHE NFOTABONG ATHEULL[1,2], NDONGO DIN[2] AND FARID DAHDOUH-GUEBAS[1,3]

[1]Laboratory of Systems Ecology and Resource Management, c/o Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles – ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium.
[2]The University of Douala, Faculty of Science, Department of Botany, Douala, Cameroon.
[3]Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussel - VUB, Pleinlaan 2, B-1050 Brussels, Belgium.

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ABSTRACT

In the present situation of coastal habitat vulnerability, qualitative and quantitative characterization of mangrove vegetation structure and dynamics is of great interest. In this context, we qualified and quantified changes in mangrove forests around Douala, Cameroon, by digitizing a time series of aerial photography from the period 1974-2009. Additionally, we assessed the mangrove structure in 2009 following the PCQM+ protocol. Our results indicated that the pristine mangroves observed in the 1974 photograph have been disturbed markedly in the 2003 and 2009 air-borne imageries. It was found that some of the pre-existing mangroves were entirely replaced by settlements, road and crops (maize, bean, banana, oil palm, green vegetables and sugar cane plantations). Over the pre-2003 period, 39.86% of mangrove forests have disappeared. Likewise, there was a net loss of 22.10% of mangrove areas from 2003 to 2009. Over the 35-year period, mangrove had decreases in cover of 53.16% around Douala. On the expense of mangrove habitat loss, a substantial increase of settlement (60%), road (233.33%), agriculture (16%), non-mangrove (193.33) and water (152.94%) areas has occurred. In addition to these results, data from field survey showed that almost one-third of the total quadrants established across the remaining mangrove forest were empty. The findings of this study highlight the necessity to create awareness amongst the local inhabitants on the importance of mangroves as well as enforcement of the existing rules to protect mangroves. This would allow maintaining ecological integrity and conserving biodiversity in endangered coastal ecosystems such as mangrove forests.

Keywords: Peri-urban mangrove, aerial photography, remote sensing; forest loss, Wouri estuary, Douala (Cameroon)

4.1 INTRODUCTION

In spite of the current context of international decisions to reduce CO_2 emission due to deforestation and forest degradation (UNFCC 2007), the rate of mangrove loss is still high in many developing countries (Duke *et al.*, 2007; Giri *et al.*, 2007), possibly higher than in any other type of tropical forests (Rakotomavo & Fromard 2010). The causes of damages included natural disasters (Dahdouh-Guebas & Koedam 2006a; Mukherjee *et al.*, 2010), sea-level rise (Di Nitto *et al.*, 2008; Shearman 2010), over-harvesting (Walters *et al.*, 2008; Nfotabong Atheull *et al.*, 2009), agriculture (Hossain *et al.*, 2009), conversion into shrimp farming ponds (Guimarães *et al.*, 2010) and other coastal land use development projects.

Although moderate natural expansion of mangrove has been reported in certain parts of the world (McKee 2004; Chimner *et al.*, 2006; Eslami-Andargoli *et al.*, 2009; Everitt *et al.*, 2010), this phenomenon is relatively rare in Africa (FAO 2007) where mangrove deforestation and degradation is still evident (Dahdouh-Guebas *et al.*, 2004a; UNEP 2007; Mmom & Arokoyu 2010; Rakotomavo & Fromard 2010). According to Food and Agriculture Organization (FAO) and United Nations Environment Programme (UNEP), Cameroon has lost approximately 22,000 ha of mangroves between 1980 and 2005 (FAO 2007; UNEP 2007). But, as stated by Kovacs *et al.* (2010), this estimation is only based on figures taken from several reports which do not contain detailed explanations of the data employed and/or lack of precision regarding the methods used to infer the subsequent results.

With regard to the reports of the World Mangrove Atlas (first edition Spalding *et al.*, 1997) and the World Atlas of Mangroves (second edition Spalding *et al.*, 2010), almost 53,216 ha of the Cameroon's mangrove forests have been lost over the last 13 years. This estimation may likely have considerable margins error since mangrove areas are not mapped at very higher level of resolution (only satellite images with spatial resolution of 30 m are used). As a result some smaller stands of mangrove like those located in the Southern part of the Cameroon's coastline may have been missed (Dahdouh-Guebas 2011). Therefore, it is crucial to accurately assess both temporal and spatial changes in mangrove forests available in Cameroon.

In addition, mangrove disturbances have been attributed to a combination of factors such as the ever-increasing human pressure on coastal lands, absence of adequate legislation for mangrove protection and pollution in the peri-urban settling of Douala (Cameroon) (Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009). Under such disrupted conditions, one approach to assess vegetation dynamics is through successive field sampling and measurements (monthly, seasonal, annual..). On the other hand, it is difficult to employ conventional field monitoring techniques in mangroves due to its harsh environment (muddy substrate, entangle root systems). As an alternative, local people's knowledge can be used for reconstructing changes that have occurred in their surrounding environment (Kovacs 2000; Dahdouh-Guebas *et al*., 2005b). But their perception of changes should be compared with quantitative data obtained through air-borne or space-borne remote sensing. In fact , these techniques provide a timely, cost-effective means to obtain reliable information over less accessible areas such as mangroves (Dahdouh-Guebas *et al*., 2000b; Verheyden *et al*., 2002; Krause *et al*., 2004; Satapathy *et al*., 2007; Everitt *et al*., 2010; Shearman 2010; Heumann 2011).

In this paper, we used three times series panchromatic aerial photographs coupled with extensive ground surveys to accurately map and estimate mangrove vegetation changes around Douala (Cameroon). By doing, we also characterize the mangrove vegetation structure. This peri-urban area was particularly interesting to quantitatively and qualitatively assess the influence of anthropogenic activities on mangrove vegetation structure and dynamics.

4.2 MATERIAL AND METHODS

4.2.1 *Study area*

The study site is located in the vicinity of the major city of Douala (Cameroon), extending *ca*. 5.8 km^2, adjacent to the airport, seaport and several settlements (Fig. 4.1). It represents *ca*. 0.53% of the mangrove cover in the Cameroon estuary.

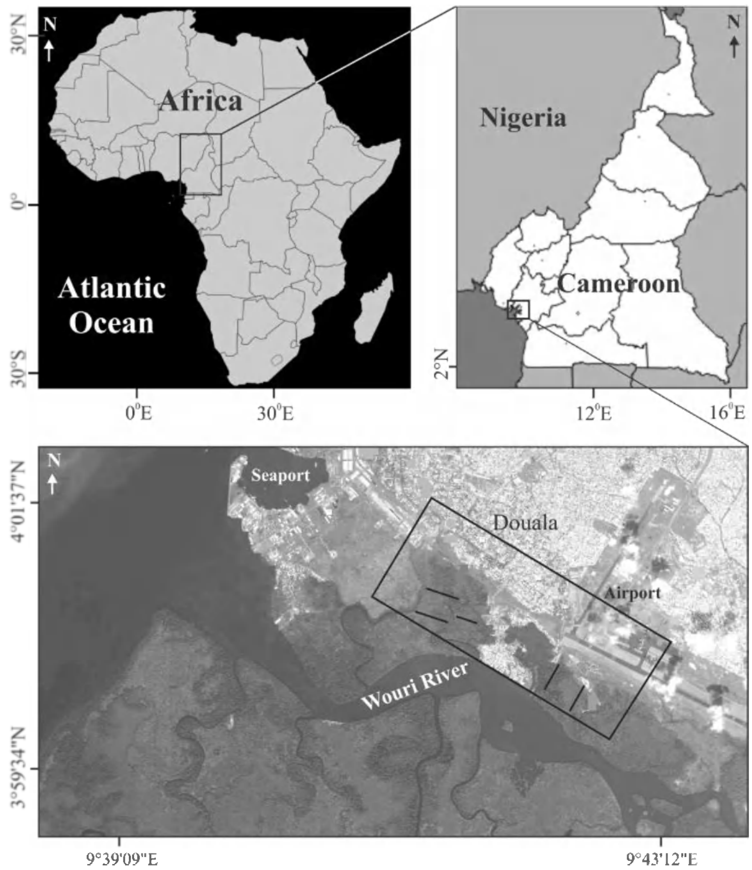

FIG. 4.1 Map showing the location of the study area and transect lines.

The availability of diachronic aerial photographs is also another reason for this (study) area selection. The climate in the region is characterized by higher rainfall (~9 months of rainy season) with a mean temperature of about 26.5°C. The tides are semi-diurnal with a mean amplitude of 1.65 m. Douala is the first most populous city in Cameroon. The population of this city has grown rapidly since 1987 (1,352 833 inhabitants) and reached to 2,510 263 people in 2005 (Cameroon National Institute of Statistics 2009). The majority of coastal communities are dependent on the surrounding mangroves for their subsistence and commercial utilizations (Din *et al*., 2008; Nfotabong Atheull *et al*., 2009). Here, mangroves are under severe pressure from several adjacent land uses.

4.2.2 *Field data collection*

Vegetation sampling was carried out between January and February 2009 following the PCQM+ protocol (Dahdouh-Guebas & Koedam 2006b). Nearby the water edge, we established the first sampling point that corresponded to the centre of four quadrants (a quadrant dimension was set to 10 m × 10 m). Then, following a clockwise direction, we used a measuring tape to measure the distance between the sampling point and the nearest tree in each quadrant. Only trees with stem diameter > 2.5 cm were sampled (*cf.* Kairo *et al*., 2002). We identified each sampled tree, measured diameter using a measuring tape and measured height with a clinometer. We applied the same methodological procedure for five different transects established perpendicular to the main creeks. Thereafter, additional field checks (visual observation) were made between March and July 2010 to characterize mangrove changes qualitatively.

4.2.3 *Calculation of structural attributes*

Since we have recorded empty quadrants during our field campain, we found relevant to employ a correction factor when calculating the absolute density of the whole mangrove forest. We used the formula proposed by Warde & Petranka (1981) and also developed by Dahdouh-Guebas & Koedam (2006b) and Mitchell (2007).

Absolute density (corrected): $$\overline{\lambda_c} = \frac{(4n - n_0)^2}{\left(\sum_{m=1}^{4n-n_0} R_m\right)^2} \times CF$$

where n is the number of sampling point, $4n$ is the number of sampling quadrants, n_0 is the number of empty quadrants, R_m is the distance from tree m to its corresponding sampling point. Different values of C.F. corresponding to the proportion of empty quadrants ($n_0/4n$) are given in Table 1 of Warde & Petranka (1981).

The absolute density, basal area, absolute frequency, relative density, relative frequency relative basal area and importance value of each species as well as the complexity index of the residual mangrove forests were calculated using the standard formulae given below:

Absolute density of each species *k*: $\overline{\lambda_k} = \frac{Number\ of\ quadrants\ with\ species\ k}{4n} \times \overline{\lambda_c}$

Basal area (cover or dominance) of species *k*: $= \frac{\Pi \times diameter^2}{4}$

Absolute frequency of species *k*: $= \frac{Number\ of\ n\ with\ species\ k}{Total\ number\ of\ n} \times 100$

Relative density of species *k*: $= \frac{Number\ of\ quadrants\ with\ species\ k}{4n} \times 100$

Relative frequency of species *k*: $= \frac{Absolute\ frequency\ of\ species\ k}{Total\ frequency\ of\ all\ species} \times 100$

Relative basal area of species *k*: $= \frac{Total\ basal\ area\ of\ species\ k}{Total\ basal\ area\ of\ all\ species} \times 100$

Importance value of species *k*: $= Relative\ density + Relative\ frequency + Relative\ basal\ area$

Complexity index (C.I.) $= Number\ of\ species \times Mean\ height \times Mean\ density \times mean\ basal\ area \times 10^{-5}$

4.2.4 *Air-borne imagery analysis*

Panchromatic aerial photographs were obtained from the Cameroon's National Center of Cartography and the Douala Urban Council. These photos were acquired for 1974, 2003 and 2009 at a nominal scale of 1:10000, 1:8000 and 1:12000, respectively. An airplane equipped with a camera (focal length of 152.81 mm) was used to obtain the 1974, 2003 and 2009 photographs from a flight (E-W lines) altitude of *ca.* 3400 m, 3200 m and 3820 m above the sea level, respectively. The lateral recovery band between two successive films ranged from 20 to 25%. The 1974 and 2009 aerial photographs (1974 and 2009) were taken at low tide whereas the 2003 aerial photograph was obtained at high-tide.

In order to assess both temporal and spatial changes in mangrove vegetation, the aerial photographs were scanned at 600 dots per inch with a pixel resolution of 0.45 m, 0.5 m and 0.60 m for 1974, 2003 and 2009, respectively. They were directly imported into ArcGIS (ESRI Inc. version 9.3) software, assembled in mosaic and geo-referenced to UTM Zone 32N WGS 84 projection using topographic maps obtained from the Cameroon National Center of Cartography (rectification of the 1974 photograph) and the Douala Urban Council (rectification of the 2003 and 2009 photographs). A minimum of twelve ground control points present in both the topographic map and aerial photograph and a 2nd-order polynomial transform were used to georectify the digital aerial photographs. The root mean square (RMS) error for all geo-registered images was less than 0.3 m.

We found to be impossible to accurately map the areal extent of different species of *Rhizophora* since they were not visually distinguishable on the black and white photoghaphs. Because *Rhizophora* spp. has been described as the most abundant mangrove species in the Cameroon estuary (Van Campo & Bengo 2004; Din *et al*., 2008; Nfotabong Atheull *et al*., 2009), we judged relevant to combine all species (*e.i*., *Rhizophora racemosa* Meyer, *R. harrisonii* L., *Avicennia germinans* (L.) Stearn, *Laguncularia racemosa* (L.) Gaertn. f., *Conocarpus erectus* L. and "*Guibourtia demensei* (Harms)) growing in our study area under the term "mangrove" (see Chimner *et al*., 2006).

Different land features were firstly differentiated with regard to the image tonalities (scale of brightness (light, medium, dark) of objects on aerial photographs). In the mosaicked photographs, mangroves have light grey to dark grey tones whereas settlements as well as roads and sand quarry have white tonal responses. Agricultural lands and other vegetation types (grassland, fallow land and ornamental woody species) have medium-grey tone, bare soil has a whitish-gray tone. Runway (airport area) has dark to light dark color whereas water displays grey appearance. We mapped the mangrove cover as well as open water areas and other types of land uses through on-screen digitization.

During high tide, the disrupted mangrove stands on the 2003 aerial photograph appeared with sea water. At first glance, one may think that this disrupted and inundated stands have already stated to rejuvenate. In such case, the juvenile or young vegetation should likely appear on the 2009 aerial photograph that was taken during low tide. *A contrario*, after a visual analysis of this aerial photograph, we noticed that the disrupted mangrove stands appeared as bare soil. As it was impossible to manually map the bounderies between water and bare soil on the 2003 areal photograph, we digitized the disrupted mangrove stands with and without water as a single class called water.

Afterwards, we delineated mangroves habitats by manually digitizing the outer edge of the canopy based on visual contrasts and referenced field data (D'Iorio *et al*., 2007). We classified the mangrove forest types based on the crown textural properties (shape, size and spatial distribution of artificial gaps, crown aggregation). We characterized mangroves with closed canopy as undisturbed forests. We categorized mangroves that displayed sparse smaller gaps as less disturbed and those that exhibited frequent large gaps as much disrupted. After digitizing all aforesaid land features, we calculated the rate of changes in mangrove cover from 1974 to 2009 using the ArcGIS intersect function. We compared the annual means of mangrove loss between the two sampling periods (1974-2003 and 2003-2009) using the Student t-test.

4.3 RESULTS

4.3.1 *Qualitative changes in mangrove vegetation*

Over a span of 35 years, patterns of qualitative changes in mangrove vegetation structure were evident in the study area. The extensive pristine mangrove, with closed canopy, observed in the 1974 photograph appeared as small sparse tree patches (strongly disturbed mangroves) or forest with few artificial canopy gaps (less disturbed mangroves) in the 2003 and 2009 air-borne imageries (Fig. 4.2, see also Fig. 4.3).

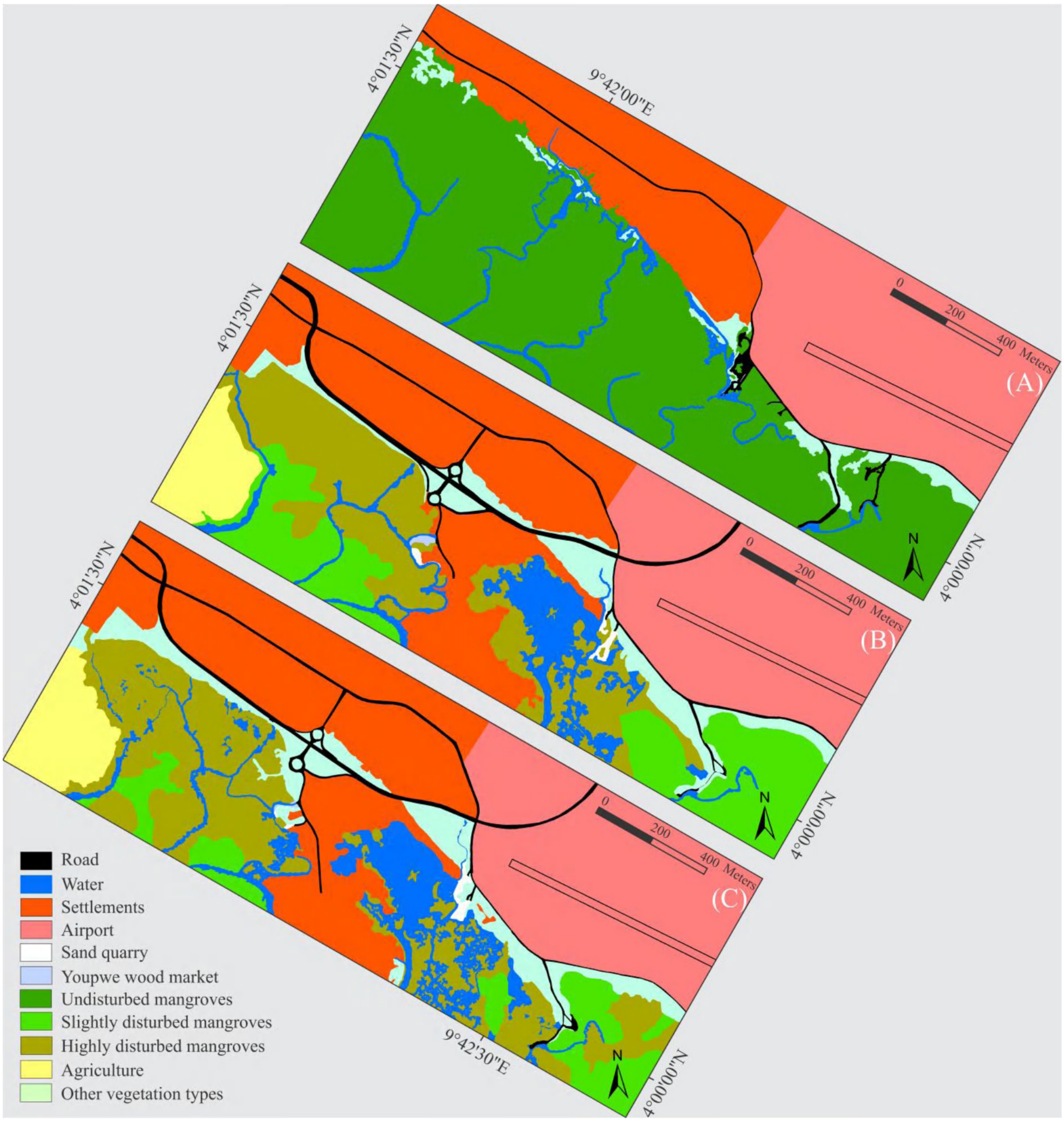

FIG. 4.2 Land use/cover map around Douala (Cameroon) at (A) 1974, (B) 2003 and (C) 2009.

As partly exemplified in Figure 4.3 (see also Fig. 4.2), some clear-felled mangrove areas are occupied by settlements or covered by the brackish water during the high tide.

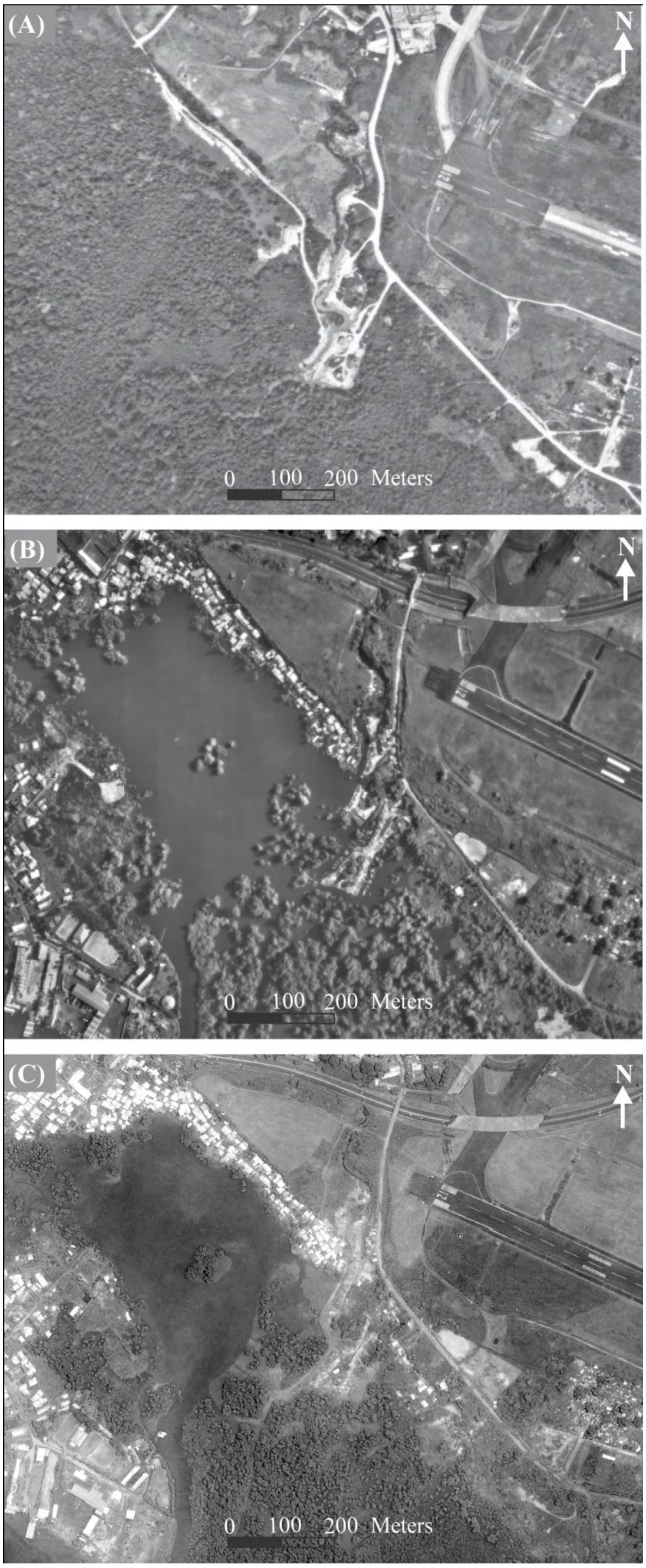

FIG. 4.3 Three time series photographs of land use/cover patterns illustrating mangrove vegetation structure dynamics in (A) 1974, (B) 2003 and (C) 2009. Notice that the 1974 and 2003 photographs were obtained during high tide whereas the acquisition period of the 2009 photograph coincided with the low tide. The newly large open water area occurring in the 2003 and 2009 photographs (B and C) is used by the local inhabitants for sand and gravel extraction.

Generally settlements are located in the intertidal zone at higher elevation where inundation is less frequent (dyke establishment often modified the water flow). Other noticeable causes of qualitative change in mangrove structure are related to its conversion into agricultural ponds (Fig. 4.4).

FIG. 4.4 Conversion of mangrove stands into agriculture areas around Douala (Cameroon). On the left side of the photo, one could observe a remnant tree of *Rhizophora* spp. Behind this tree, there are two farmers working within a plantation of maize, bean, banana, oil palm, green vegetables and sugar cane. The level of salinity is moderate because of the landward position of plantations and the high rate of water dilution throughout the year (at least 9 months of wet season). These plants might likely be affected by prolonged exposure to extreme acidity and toxic ions such as Fe^{2+}, S^{2-}, Mn^{2+}, etc.

In addition, some peri-urban mangrove forests have been flattened by bulldozers to make roadways. Mixed vegetation was present on the three time series photographs (Fig. 4.2).

During the field survey in 2009, *Nypa fruticans* was found growing in large open areas and along the muddy river front. This introduced mangrove species also occurred under the canopy of less degraded mangrove forests and therefore not possible to accurately delineate its distribution through on-screen digitization. Mixed vegetative stands consisting *Hibiscus tiliaceus* L., *Acrostichum aureum* L., *Ormocarpum verrucosum* P. Beauv., *Phoenix reclinata* Jacq., *Drepanocarpus lunatus* G. F. Meyer, *Raphia palma-pinus* (Gaertn.) Hutch., *Cynometra mannii* Oliv., *Pandanus candelabrum* P. Beauv. and *Dalbergia ecastaphyllum* (L.) Taub. were sometimes observed along the less muddy shorefronts.

4.3.2 *Quantitative changes in mangrove vegetation*

A trend of decrease mangroves was observed between 1974 and 2009 in the study site. In 1974, mangrove forests covered 51.89% (3.01 km^2) of the study site, whereas in 2003 it was 31.20% (1.81 km^2), indicating a decrease of 39.86% over the 29-year period (Table 4.1).

Table 4.1 Land use/cover changes derived from 1974, 2003 and 2009 aerial photographs of Douala (Cameroon) peri-urban setting.

Land use/cover	Area at 1974		Area at 2003		Area at 2009		Change 1974 - 2003	Change 2003 - 2009	Total change from 1974 to 2009
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(%)	(%)	(%)
Mangroves	3.01	51.89	1.81	31.20	1.41	24.29	-39.86	-22.1	-53.16
Settlements	1.05	18.11	1.57	27.06	1.68	28.94	49.52	7	60
Agriculture	–	–	0.25	4.31	0.29	4.99	–	16	–
Other vegetation types	0.15	2.59	0.34	5.86	0.43	7.41	126.66	29.41	193.33
Water	0.17	2.93	0.33	5.69	0.43	7.41	94.11	30.3	152.94
Road	0.06	1.03	0.15	2.58	0.2	3.44	150	33.33	233.33
Sand quarry	–	–	0.01	0.17	0.01	0.17	–	0	–
Youpwe wood market	–	–	0.002	0.03	0.006	0.10	–	66.67	–
Airport	1.36	23	1.34	23	1.35	23	-1.47	0	0

In the 2009 photograph, mangroves represented 24.29% (1.41 km^2) of the study site, a decrease of 22.10% to that of 2003. For the overall 35-year period from 1974 to 2009, the decrease in mangrove cover was of about 53.16%.

Between 2003 and 2009, the coverage of less disturbed mangrove forests decreased from 44.20% to 20.57% representing a decrease of 63.75% over the 6-year period (Table 4.2). In contrast, the rate of change in large disturbed mangrove extend after 2003 was ranged from 55.80% to 79.43%, amouting to an increase of 10.89% between 2003 and 2009.

In 1974, settlements made up 18.11% (1.05 km^2) of the study site, whereas in 2009 they extended to 28.94% (1.68 km^2) with an increase of 60% over the 35-year period. The increase in areas occupied by water, road, agricultural land, sand querry, wood market and other vegetation types is shown in Table 4.1.

Notice that the unbalanced sampling period could bias any effective comparison of mangrove loss between the two sampling period (1974-2003 and 2003-2009). However, there was no significant difference between the first (prior 2003) and second (after 2003) study periods in terms of annual means (1.37% and 3.68%, respectively) of mangrove loss ($t = -0.44$; d.f. = 1; $p > 0.05$).

Table 4.2 Area and rate of changes of different mangrove types between 2003 and 2009 in a peri-urban setting of Douala (Cameroon).

Land use/cover	Area at 2003		Area at 2009		Change 2003 - 2009
	(km^2)	(%)	(km^2)	(%)	(%)
Mangroves					
Slightly disturbed	0.80	44.20	0.29	20.57	-63.75
Highly disturbed	1.01	55.80	1.12	79.43	10.89

4.3.3 *Current state of the mangrove forest*

During the field survey in 2009, 30.31% of the total sampled quadrants were found without mangrove trees. We recorded five native mangrove species (*Rhizophora racemosa* Meyer, *R. harrisonii* Leechman, *Avicennia germinans* (L.) Stearn, *Laguncularia racemosa* (L.) Gaertn. f. and *Conocarpus erectus* L.), along with one mangrove associated species (*Guibourtia demensei* (Harms) and one introduced mangrove species (*Nypa fruticans* Thurnb. Wurmb.) in the study area. The mangrove forest has an overall mean height, absolute density and basal area of 19.80 m, 158 trees ha^{-1} and 110.44 m^2 ha^{-1}, respectively. This disrupted ecosystem was more complex (C.I. = 20.78) in terms of the number of species growing in the area. The structural characteristics of each mangrove species is summarized in Table 4.3. Based on the importance value (I.V.), *R. racemosa* was abundant followed by *A. germinans*, *R. harrisonii* and *G. demensei* (Table 4.3). The species *G. demensei* was often found at eleva-

Table 4.3 Structural characteristics of mangrove forests in a peri-urban setting of Douala (Cameroon).

Species	Number of individuals	Mean height (m)	Mean diameter (cm)	De (trees ha^{-1})	BA (m^2 ha^{-1})	F (%)	De_r (%)	BA_r (%)	F_r (%)	I.V.	Rank	C.I
Rhizophora racemosa	134	18.46 ± 8.56	20.92 ± 16.16	95.89	49.31	81.25	42.19	44.65	48.51	135.35	1	20.78
Avicennia germinans	54	25.99 ± 9.59	38.46 ± 19.75	38.35	55.38	43.75	16.87	50.15	26.12	93.14	2	
Rhizophora harrisonii	21	16.05 ± 7.23	15.98 ± 8.55	14.91	3.91	26.25	6.56	3.54	15.67	25.77	3	
Guibourtia demensei	6	16.18 ± 5.90	14.12 ± 11.40	4.26	0.9	7.50	1.87	0.81	4.48	7.16	4	
Laguncularia racemosa	4	17.76 ± 3.77	17.70 ± 7.01	2.84	0.77	5,00	1.25	0.70	2.99	4.94	5	
Conocarpus erectus	3	12.31 ± 4.33	9.31 ± 4.68	2.13	0.17	3.75	0.94	0.15	2.23	3.32	6	

Notice that De = Absolute density; BA = Basal area; F = Absolute frequency; De_r = Relative density; BA_r = Relative basal area; F_r=Relative frequency; I.V. = Importance Value; C.I = Complexity index.

ted ground behind a population of true mangrove species.

During the field checks carried out between March and July 2010, significant changes in mangrove vegetation structure were observed in the study area. In fact, as exemplified in Fig. 4.5, the previously large disturbed mangrove forests (with reference the 2009 field sampling), easily accessible by foot, were progressively clear-cut from the landward margin towards the main water channel. Afterwards, the unvegetated areas would be used for housing.

FIG. 4.5 A view of a clear-cut mangrove stand in the peri-urban setting of Douala (Cameroon). The large disturbed *Rhizophora* spp. stand is clear-felled for wood collection and housing.

In the sites only accessible by boats, the lower stratum of the highly disturbed stands are consist of *Rhizophora* propagules (juvenile mangroves) that growed amongst stumps, branches and cut trunks lying on forest floor. Young trees of *Rhizophora* were found growing in some old large disrupted mangrove stands. The slightly disturbed mangrove sites were composed either of monospecific stands of *Rhizophora* spp. (mature trees) or mixed population of *Rhizophora* spp. and *A. germinans*. The upper stratum of these mixed formations was composed of *A. germinans* (adult trees) whereas the middle stratum was made up of youngest individuals of *Rhizophora* spp. and *A. germinans*. In such stands, juvenile trees were less frequent.

4.4 DISCUSSION

The present study has been carried out in an area where several anthropogenic factors (*e.g.*, over-harvesting, anarchic urbanization, agriculture, industrial pollution, sand extraction) are responsible for a decrease in the mangrove cover. In fact, we have qualitatively and quantitatively documented the effect of each anthropogenic activity in the reduction of mangrove cover around Douala (Cameroon). Although our study has been carried out on a discrete location, the findings are of great concern especially in the current context where mangroves are decreasing all over the world at an alarming rate (Giri *et al.*, 2007). To ensure that future generations enjoy the ecosystem services provided by such valuable natural ecosystems, there is an urgent need to detect, protect, restore degraded tidal forests (Duke *et al.*, 2007) and preserve remaining natural mangrove systems.

Though mangroves are legally protected in Cameroon, the results of this study have shown that there was an effective loss of 53.16% of mangrove forests in the peri-urban settings of Douala in 35-year period. The aforementioned rate of mangrove decrease is almost two times higher than the worldwide estimates rate (~35% of mangrove loss between 1980 and 2000) of tidal forest degradation (Valiela *et al.*, 2001). Likewise, our estimation is so far different to that recorded by UNEP (2007) and FAO (2007) between 1980 and 2005 in Cameroon. Indeed, these two organisations of the United Nations suggest that Cameroon has loss *ca.* 8.08% of mangrove between 1980 and 2005. The large difference between their estimation and that recorded here may be related to the relatively small extent of our study area (we are looking at 0.15% of the total mangrove area in Cameroon) and its proximity to the heavily populated coastal zones.

The primary threats to all mangrove species are habitat destruction and removal of mangrove areas for conversion to aquaculture, agriculture, urban and coastal development, and overexploitation (Hossain *et al.*, 2009; Polidoro *et al.*, 2010; Guimarães *et al.*, 2010). Of these, the contribution of land development project (anarchic urbanization) to the reduction of mangrove cover is considerable in our study area. Comparison between the 1974, 2003 and 2009 photographs clearly revealed the encroachment of human settlements into mangrove ecosystems.

Mangrove forest regression is often the result of heavy pressure from human habitation (Rakotomavo & Fromard 2010) or changes in open-mouth conditions and intertidal habitat (Dahdouh-Guebas *et al.*, 2005b; Rajkaran *et al.*, 2010). For instance, in the Wouri estuary, mangrove ecosystems are traditionally harvested for the production of firewood, charcoal, boats, fish-traps, timber and poles for houses (Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009). This may explained the lack of significant difference in the mean annual rate of mangrove loss between the two sampling periods. Though trees of *Rhizophora racemosa* are commonly harvested, because of their frequency they turn out to be the most important species within the disrupted mangrove forests (see Table 4.3). The lower abundance of *Rhizophora* trees that exceeded 20 cm in diameter may be related to their collection for commercial purposes (Nfotabong Atheull *et al.*, 2009). This is not true for *Avicennia germinans* trees which currently showed large basal area (small number of trees with stem diameter > 30 cm) in the residual mangrove forests. In contrast to the previous findings (Din *et al.* 2002), seeds and seedlings of this black mangrove were scarce around the adult trees. The relatively closed canopy might be unfavourable for the germination and growth of the heliophilous *Avicennia* propagules (Patterson *et al*., 1993; McKee 1995; Fromard *et al*., 2004; Pickens & Hester 2011).

The negative impact of plant harvesting on the health of mangrove forests is illustrated by the presence of numerous small tree patches surrounded by water bodies (see Fig. 4.2 B, C). As a consequence of tree harvesting, some of the water channels previously covered by tree crown in the 2003 photograph have become visible in the 2009 airborne imagery. In contrast, visual interpretation of the photographs coupled with field observations revealed that a few part of previously large disturbed mangrove forests have successfully rejuvenated at present. Young individuals of *Rhizophora* spp. were predominant in such areas.

Although there was a relatively slight increase in the width of water channels, we assume that the aforesaid procedure could have led to an overestimation of the rate of water increase over the 35-year period.

The improvements to the city's transport infrastructure appear also as a factor contributing to mangrove encroachment in the supra-littoral zones (landward edge) of our study site. Indeed, road construction often led to an ultimately modification of the surrounding habitat which become favourable to the establishment of non-mangrove species. Moreover, in the high intertidal zone, mangroves are cleared for development of agriculture. The development of such anthropogenic activity in the upstream estuarine zones is likely due to the fact that these areas often have low sea water supply.

Although none of the mangrove species present in Cameroon have been listed in threatened categories (Polidoro *et al*., 2010), populations are more at risk from habitat loss. The regression of mangrove forest is exacerbated by the masses of migrants recently arriving from villages. As many peri-urban mangrove areas around Douala are accessible by foot, these migrants have cleared mangrove forests for wood collection and housing. This mangrove habitat disruption can affect the hydrodynamic processes, leading to a reduction of commercial fish and shellfish species that breed, spawn, hatch or develop in the mangrove ecosystems (Barbier 2003; Mumby *et al*., 2004). With a rise in sea level, the habitat of the remaining mangrove species will be furthermore disrupted (Gilman *et al*., 2008), and species zones will suffer mortality since their movement inland would be blocked by coastal development (Polidoro *et al*., 2010).

4.5 CONCLUSION

The present study highlights the potential of air-borne imagery for qualitative and quantitative characterization of mangrove vegetation dynamics over three decades. These kinds of studies are of great concern especially in the current context of vulnerability of coastal ecosystems to the changes associated with anthropogenic activities and global warming. Our results clearly revealed a considerable decrease of mangrove cover in the vicinity of Douala, Cameroon. This coastal ecosystem is continuously cleared for the purpose of other land-use activities such as settlements, road construction, sand quarry and agriculture. The disruption of mangrove habitat could lead to the loss of individual mangrove species and associated ecosystem services (Polidoro *et al.*, 2010). It is therefore necessary to create awareness amongst the locales as well as enforce the local existing conservation rules.

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PLANCHE 5. Une souche de *Rhizophora* spp. (flèche noire) et un quelques arbres d'*Avicennia germinans* (L.) Stearn (flèche grise) observés dans un site de mangrove perturbé à Mboussa Essengue (Douala, Cameroun).

PLATE 5. Stump of *Rhizophora* spp. (black arrow) and live trees of *Avicennia germinans* (L.) Stearn (grey arrow) recorded in a disturbed mangrove stand of Mboussa Essengue (Douala, Cameroon).

CHAPTER 5

RECONSTRUCTION OF FOREST STRUCTURE IN THE HUMAN-INFLUENCED MANGROVES OF DOUALA (CAMEROON) USING A HINDCASTING APPROACH WITH AN INDIVIDUAL-BASED MODEL

ADOLPHE NFOTABONG ATHEULL[1,2], ARMIN KOLLERT[3], NDONGO DIN[2], SAMUEL R. L. GWETH[2], GUILLAUME L. ESSOMÈ KOUM[2], UTA BERGER[3] AND FARID DAHDOUH-GUEBAS[1,4]

[1]Laboratory of Systems Ecology and Resource Management, c/o Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles – ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium.
[2]The University of Douala, Faculty of Science, Department of Botany, P.O. Box 8948 Douala Cameroon.
[3]Department of Forest Biometry and Systems Analysis, Institute of Forest Growth and Forest Computer Sciences, Technische Universität Dresden, Germany.
[4]Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussel - VUB, Pleinlaan 2, B-1050 Brussels, Belgium.

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ABSTRACT

The impact of anthropogenic disturbances on mangrove vegetation structure and dynamics are common along the tropical and subtropical coastlines. Botanists have established reliable models that allow the characterization of current spatial structure and development of forests. Yet, the computation of such models do not often take into account the structural features of cut trees, although the latter are quite useful for understanding and characterizing of past, present and future evolution of the forest stands. In this study, the past mangrove forest structure around Douala (Cameroon) was characterized by calculating the complexity index (an estimator of the spatial structure and development of forests) based on trees and stump structural parameters. The subsequent result of this first methodological approach was checked by hindcasting the assumed structure of the original forest (before cutting), modelling the development of that forest using an individual-based model, and evaluating the plausibility of different management scenarios (without mortality and cutting; mortality and cutting; non-selective cutting of 50% of all species; selective cutting of 50% of each species; cutting according to stump diameter distribution). In Mboussa Essengue as well as in Bois de Singes, the complexity index was higher prior to harvest than it was at the time of recording the data. The higher complexity index in Mboussa Essengue indicates that this peri-urban forest was structurally more complex (muti-species stand comprising large number of trees with low or medium size) prior to harvesting. Likewise, the original mangrove forest in Bois de Singes was structurally more developed (single-species stand mainly composed of large trees with stem diameter > 20 cm). Here, a non-selective cutting of 50% of the trees is most plausible but there is no large difference to a cut according to the diameter distribution. In Mboussa Essengue, however, loggers selectively cut the most frequent tree diameter class (< 10 cm). This paper highlights the potential of combining empirical and modelling approaches to reconstruct past forest structure and infer management impacts. The findings are useful for monitoring human impacts on mangrove and we believe that this method can also be applied in a wide range to other harvested forest sites.

Keywords: Complexity index, individual-based model, tree stumps, cutting, disturbance, peri-urban mangroves, Douala (Cameroon)

5.1 INTRODUCTION

Found along (sub)tropical coastlines, mangrove forests are intertidal forests that protects coastal communities against natural hazards such as tsunamis, cyclones and hurricanes (Dahdouh-Guebas 2006; Alongi 2008). Mangroves provide a habitat for many fish and shelfish species (Nagelkerken *et al.*, 2008) and also generate wood and non-wood products that are important for local livelihoods and national economies (Walters *et al.*, 2008). In spite of their biological, economical and ecological values, mangrove ecosystems continue to be greatly degraded because of sea level rise (Gilman *et al.*, 2008; Di Nitto *et al.*, 2008), herbivore pressure (Cannicci *et al.*, 2008) and most importantly increased anthropogenic disturbances (Valiela *et al.*, 2001; Duke *et al.*, 2007).

Rapid population growth increasingly threatens peri-urban mangrove forests especially in developing countries where government policy-makers still pay little attention to protect these coastal ecosystems (Duke & Schwarzbach 2001; Walters *et al.*, 2008). In Cameroon, human activities appear to be the main factor influencing the structure (distribution pattern of trees and cut stumps across the entire forest) and dynamics (self-regeneration of anthropogenic impacted area) of mangroves.

Apart from the conversion of these estuarine mangroves into agricultural land, urban and seeport expansion, the most important form of disturbance is tree harvesting. The three species of *Rhizophora* (*Rhizophora racemosa* Meyer, *R. mangle* L. and *R. harrisonii* Leechman) and *Avicennia germinans* (L.) Stearn (nomenclature according to Tomlinson 1986) have experienced intensive logging that has led to a significant decrease of mangroves in this region (FAO 2007; Spalding *et al.*, 2010). In addition, the highly selective tree cutting or other impacts (variation in river hydrology) resulting in cryptic or general degradation may influence forest structure (Dahdouh-Guebas *et al.*, 2005b) especially in a peri-urban forest like Douala (Cameroon) where mangroves are exposed to considerable anthropogenic pressure. Despite the fact that mangrove forests have suffered great losses in this region, little is known about their stand structure. Since the demand for mangrove wood and non-wood products is gradually increasing in Douala city (Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009), there is a need to examine the impact of human activities on the stand structure of this peri-urban mangrove forest. Understanding the dynamics and trends of anthropogenic disturbance patterns in these forests will allow both scientists as well as managers to predict future forest composition and structure (Dahdouh-Guebas *et al.*, 2002; Berger *et al.*, 2008; Obade *et al.*, 2009).

In this study, we combined empirical and modeling approaches a) to evaluate the impact of tree harvesting on forest structure, b) to reconstruct the past mangrove forest structure (computation of the complexity index of the forest prior to wood harvesting and to c) to evaluate the plausibility of different management scenarios (hindcasting approach involving an individual-based model).

5.2 MATERIALS AND METHODS

5.2.1 *Study area*

The study was conducted in two peri-urban sites (Mboussa Essengue and Bois de Singes) located in the Cameroon estuary (3°40'-4°11'N and 9°16'-9°52'E) (Fig. 5.1).

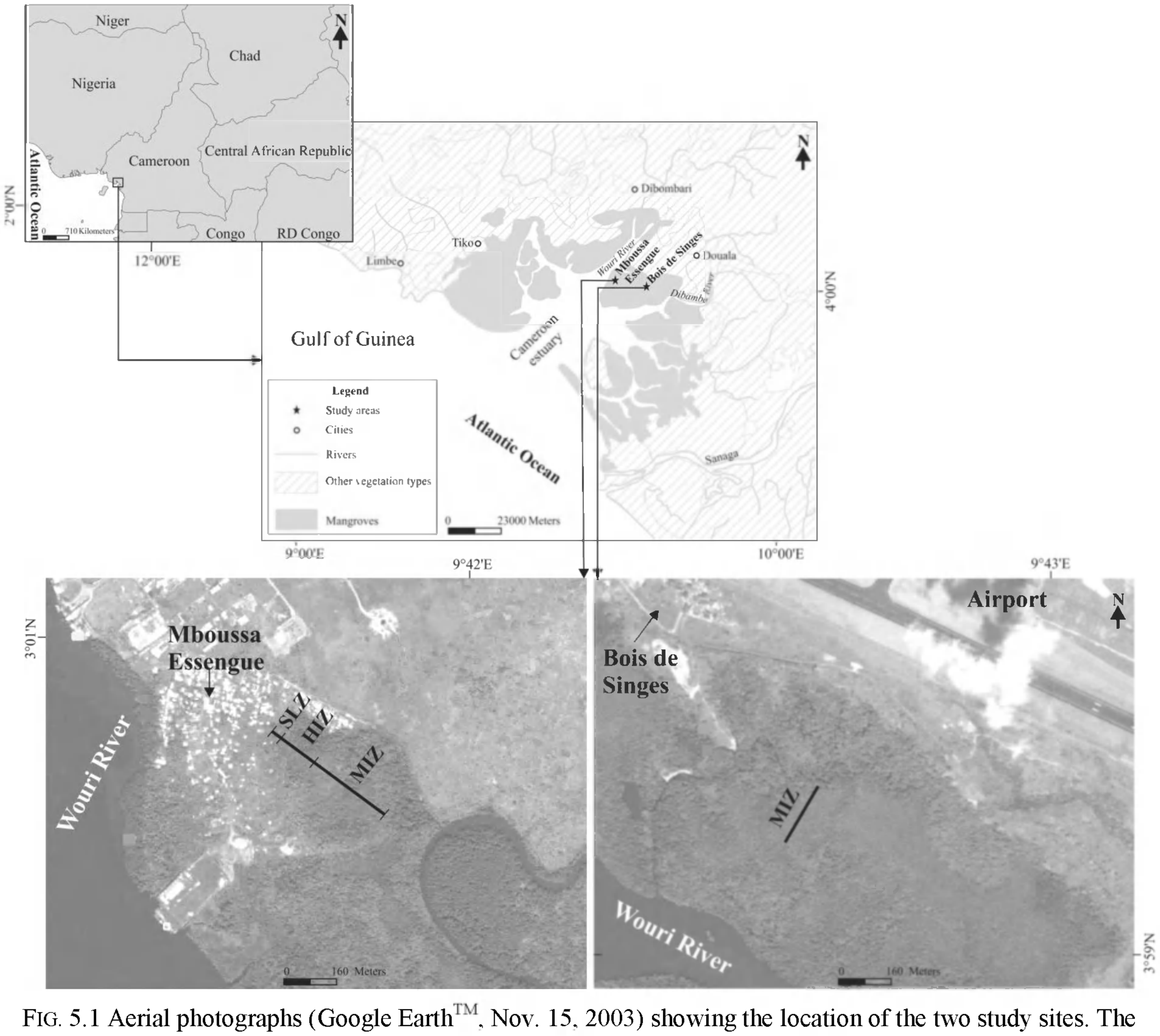

FIG. 5.1 Aerial photographs (Google Earth™, Nov. 15, 2003) showing the location of the two study sites. The straight black lines across the vegetation show the position of the belt transects. SLZ = Supra-littoral zone; HIZ = High-intertidal zone; MIZ = Mid-intertidal zone.

Tide regime in this estuary is semi-diurnal in nature with a maximum range of 3 m in the vicinity of the Douala seaport. During the longer wet season (at least 9 months), the salinity is generally null but it can reach 20‰ during the dry season. Rainfall pattern is unimodal and slightly higher during the months of July, August and September. The mean annual precipitation is 3988 mm and the average annual temperature is 26.7°C. The relative humidity of the air remains high and constant throughout the year.

Belt transects of 20 m width were laid in perpendicular to the main creek across the Mboussa Essengue and Bois de Singes mangrove forests (Fig. 5.1). In the former site, the length of the belt transect was 290 m whereas in the latter one it was 150 m. Three different zones were distinguishable across mangrove forest of Mboussa Essengue (Fig. 5.2). The first one, located in more elevated areas neighbouring human settlements, was the supra-littoral zone (SLZ) (also see Fig. 5.1). This zone has an extent of approximately 30 m. Here, the disturbed mangrove ecosystem comprised stumps and trees of *Rhizophora*, *Avicennia germinans* and *Laguncularia racemosa* (Fig. 5.2). Mangrove associated species as well as dykes were commonly observed in this area. The SLZ was fronted by a gently sloping zone (high-intertidal zone (HIZ)) that has an extent of about 90 m. The mangrove substrates in these two intertidal zones were relatively consolidated. In the HIZ, the mangrove stand was mainly composed of stumps of the three aforesaid species. The mid-intertidal zone (MIZ), located in the interior of the mangrove forest, extended 165 m away from the end of the HIZ. This MIZ formed a muddy tidal area and displayed relatively less anthropogenic interventions. The second transect established in Bois de Singes represent only MIZ. This zone was characterized by a co-dominance of stumps and trees.

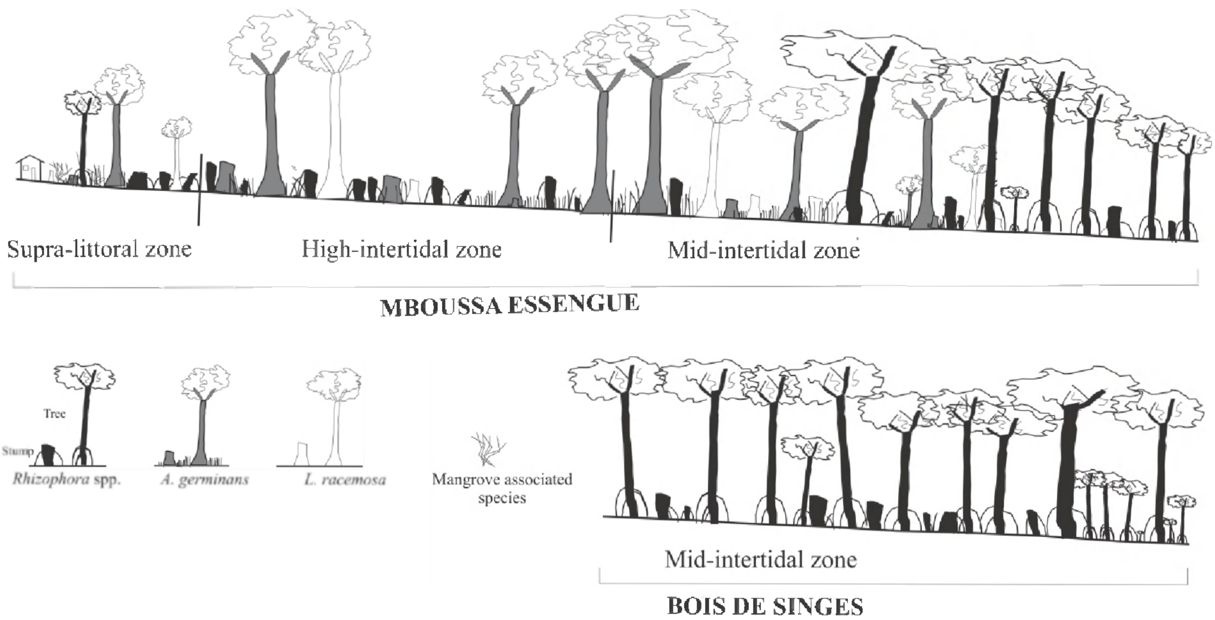

FIG. 5.2 Overview scheme illustrating the spatial arrangement of tidal zones in the two sampling sites.

5.2.2 *Tree and stump census*

Vegetation measurements were carried out between January and February 2004. The quadrat/census plot method (Cintrón & Schaeffer-Novelli 1984) was employed to assess the mangrove forest characteristics. The belt transects were divided into 20 plots of 20 m × 20 m that were numbered from 1 to 13 in Mboussa Essengue and from 14 to 20 in Bois de Singes.

In Mboussa Essengue, one, four and eigth plots were located in the supra-littoral, high and mid- intertidal zones of the mangrove forest, respectively. All plots in Bois de Singes were established in the mid-intertidal zone. The overall area sampled in Mboussa Essengue and Bois de Singes was 0.52 ha and 0.28 ha, respectively.

Stumps identification was assessed based on the difference between species' root systems. However, we were unable to distinguish stumps of the three West African species belonging to genus *Rhizophora*. Within each sample plot, all trees with a diameter > 2.5 cm and stumps were identified, counted and their position marked using a red paint mark. Trees with diameters < 2.5 cm were considered in the category ''juveniles'' (*cf.* Kairo *et al.*, 2002). The latter were not sampled in the field since they were not harvested by local communities. The stump diameters at the cutting point, as well as the tree diameters at 130 cm above the ground (D_{130}) (Brokaw & Thompson 2000) were measured using the forest calliper. Stump and tree heights were measured using a clinometer and a wooden foldable tape measure, respectively. Occurrence of snags due to natural causes within the plots was rare in the areas under study. In addition to the field sampling, some local people were asked to pronounce about the early period of wood removal in the two study sites.

5.2.3 *Reconstruction of tree height before cutting*

The basal area of trees, used for calculating the complexity index (C.I.) of the forest (Holdridge *et al.*, 1971), is commonly derived from the stem diameter measured at breast height (Cottam & Curtis 1956). Likewise, the calculation of C.I. does not take into account the stump height, but it usually relays on tree height. We also judged relevancy to reconstruct the tree height and the diameter at breast height before harvesting. Since trees are often cut at different heights, it was necessary to develop a set of allometric relationships between tree height and each stump diameter (measured at the cutting point) on one hand, and between the latter structural parameter and stem diameter (at breast height) on the other hand.

To achieve this purpose, additional vegetation measurements were carried out in May 2009 in order to assess tree height and stem diameter prior to cutting, *i.e.*, original tree height and diameter at breast height. We sampled 40 uncut trees of *Laguncularia racemosa* (L.) Gaertn. f.), 52 of *A. germinans* and 54 of *Rhizophora* spp. in an undisturbed area of the mangrove forest. For each species, we firstly measured tree height and stem diameter at 0.10 m intervals between 0.20 and 1.30 m above the ground. Then, we plotted the tree height *versus* the diameter at each measurement interval. In addition, we also computed the latter structural parameters against the D_{130}. Hence, we obtained 69 linear fits (regression equations) that were finally used to calculate tree height and stem diameter (D_{130}) before cutting (for each of the stumps found in the field). The latter structural parameter was therefore employed when calculating the basal area of the forest before cutting.

5.2.4 *Field data analysis*

The one-way ANOVA test was used to assess differences between the relative abundance of stumps and trees within the sampling areas. For each species, the volume of cut stumps with roots underground was estimated as followed:

$$V = \pi \times h \times (D/2)^2 \qquad (5.1)$$

where D is the stump diameter measured at the cutting point; h, the stump height.

The density, basal area, relative density, relative basal area and relative frequency of stumps and trees available in each sampling site were calculated using the following formulas:

$$\text{Density of species } k\text{:} = \frac{Number\ of\ individuals\ of\ species\ k \times 10000\,m^2}{Area\ of\ plot\ (in\ m^2)} (trees\ ha^{-1}) \qquad (5.2)$$

$$\text{Basal area of species } k = = 0.00007854 \times Diameter^2\ (m^2\ ha^{-1}) \qquad (5.3)$$

$$\text{Relative density of species } k\text{:} = \frac{Number\ of\ individuals\ of\ species\ k \times 100}{Total\ number\ of\ individuals\ of\ all\ species} \qquad (5.4)$$

$$\text{Relative basal area of species } k\text{:} = \frac{Basal\ area\ of\ species\ k \times 100}{Basal\ of\ all\ species} \qquad (5.5)$$

$$\text{Relative frequency of species } k\text{:} = \frac{Frequency\ of\ species\ k \times 100}{Frequency\ of\ all\ species} \qquad (5.6)$$

For each site, the importance value (I.V.) of stumps and trees was derived from the above structural parameters as the sum of relative density, relative basal area, and relative frequency (Holdridge *et al*., 1971).

Based on Holdridge *et al.* (1971) calculations, the C.I. of the current forests was estimated as the product of basal area ($m^2\ ha^{-1}$), number of species, mean tree height (m) and tree density (tree ha^{-1}) × 10^{-5}. In order to characterise the original structure of the forests, a combined C.I. for stumps and trees was calculated for each study site (we assumed that the previous forest state (prior to harvesting) consisted of stumps and current trees (if ingrowth neglected)).

$$Combined\ C.I. = Number\ of\ species \times \sum_{S=1}^{n}\sum_{T=1}^{m}(BA_S + BA_T) \times \frac{1}{n+m}\sum_{S=1}^{n}\sum_{T=1}^{m}(H_S + H_T) \times \frac{(n+m)\times 10000\,m^2}{Area\ of\ all\ plots\ (in\ m^2)} \times 10^{-5} \qquad (5.7)$$

where S = stumps; T = trees; n = total number of stumps; m = total number of trees; BA_S = total basal derived from stem diameter (at breast height) prior to cutting (see section 5.2.3);

BA_T = basal area of current trees; H_S = stem height prior to harvesting; H_T = height of current trees.

The relative abundance of stumps and trees within each plot was assessed through an ordinary dominance curve available in PRIMER *v* 6.1.10 (Clarke & Gorley 2001). In order to assess the level of disturbance (harvesting) in each sampling site, we used *k*-dominance curves (Lambshead *et al.*, 1983) in which the plots are ranked on the *x*-axis with relative abundance of stumps and trees on the *y*-axis (cumulative scale). Later on, we used the *W* index developed by Warwick (1986) to measure the extent to which the cut stumps curve is above/below the trees curve (positive value of *W* is expected for the undisturbed stands and negative value for disturbed areas).

5.2.5 *Simulation experiments*

In order to select the most plausible cutting option which could have produced the forest structure observed in both study sites, we simulated a virtual mangrove stand by means of the mangrove forest simulation model KiWi (Berger & Hildenbrandt 2000). The KiWi model is an individual-based model describing the fate of individual trees depending on their specific environmental conditions including local neighbourhood competition. The simulation experiments were conducted as follows: the model was initialised according to the forest structure being assumed for a previous moment in time (6 years before the field surveys have been carried out; according to the local people, it is at this period that the studied mangrove forests were impacted). This forest structure was reconstructed by merging the field data of living trees and stumps assuming that all previously cut trees were sampled. Another assumption for reconstructing the previous forest structure was that all living trees grow into the next higher 2 cm diameter class during the previous time period. Thus, living trees were set back one diameter class and with stumps combined to one single dataset.

Different management scenarios were applied to the virtual forest during six simulated years. The scenarios leading to the best correspondence between simulated stem diameter (D_{130}) size class distribution and the one measured for the living trees in both study sites were selected as the most plausible one. The following seven simulation scenarios were ran for the Mboussa Essengue forest:

(I) without mortality and cutting; (II) with mortality as described by Berger & Hildenbrandt (2000); (III) non-selective cutting of 50% of all trees; (IV) selective cutting of 50% of *A. germinans*; (V) selective cutting of 50% of *L. racemosa*; (VI) selective cutting of 50% of *Rhizophora* spp. (VII) cutting according to stump diameter distribution. The scenarios (IV) and (V) could not be applied to the Bois de Singes as this forest is mono-specific.

Cutting took place directly after trees were implemented, i.e. before the first simulation period could start. Mortality was allowed during all 6 simulation periods, except in scenario I. For each scenario 10 simulations were ran and then summarized by calculating the mean of each diameter class. For evaluation purposes, each obtained diameter distribution was compared with the original distribution according to the following indices adapted from Pretzsch *et al.* (2002):

$$\text{Bias: } \bar{e} = \frac{\sum_{i=1}^{n} e_i}{n} = \frac{\sum_{i=1}^{n} (x_i - X_i)}{n} \tag{5.8}$$

where n is the number of size classes; x_i, number of simulated trees in size class i; X_i, number of observed trees in size class i.

$$\text{Precision: } S_e = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{e} - X_i)^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} (e_i - \bar{e})^2}{n-1}} \tag{5.9}$$

$$\text{Accuracy: } m_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - X_i)^2}{n-1}} = \sqrt{S_e^2 - \bar{e}^2} \tag{5.10}$$

The accuracy depends on both bias and precision. The scenario producing the smallest value of m_x (*e.i.*, best accuracy) was selected as the most plausible one.

5.3 RESULTS

5.3.1 *Forest structure*

Stumps were significantly more abundant than trees across the study area (F = 36.11; d.f. = 1; P < 0.001). This was mostly the case in Mboussa Essengue where 80.40% of records were stumps (Table 5.1a). In contrast, about 59.66% of all records at site Bois de Singes were trees (Table 5.1b). In Mboussa Essengue, the ratio between stumps and trees density was 6.75, 1.73 and 1.86 for *Rhizophora* spp., *A. germinans* and *L. racemosa*, respectively (Table 5.1 a, b). In Bois de Singes, this ratio was 0.45 for *Rhizophora* spp. Moreover, our finding shows that 51.91% of stumps in Mboussa Essengue were in the lower size class (below 10.0 cm). About 46.42% of stumps in Bois de Singes were in the medium size class (between 20.1 and 30.0 cm) (Table 5.1 a). The latter size class were preferred for firewood whereas the former was devoted for housing purposes.

Table 5.1a Stumps and trees available in the Mboussa Essengue (a) and Bois de Singes (b) mangrove (Douala, Cameroon).

(a)	Mangrove taxa	Diameter class (cm)					Density (stumps ha^{-1})
		≤ 10.0	10.1-20.0	20.1-30.0	30.1-40.0	> 40.0	
Stumps	*Rhizophora* spp.	282 (47.47)	156 (26.26)	125 (21.04)	27 (4.55)	4 (0.68)	594 (49.42)
	A. germinans	236 (53.15)	81 (18.24)	110 (24.78)	17 (3.83)	0 (0)	444 (36.94)
	L. racemosa	106 (64.63)	37 (22.56)	15 (9.15)	6 (3.66)	0 (0)	164 (13.64)
	Total	**624 (51.91)**	**274 (22.8)**	**250 (20.8)**	**50 (4.16)**	**4 (0.33)**	**1202**
Trees	*Rhizophora* spp.	15 (17.05)	21 (23.86)	35 (39.77)	15 (17.05)	2 (2.27)	88 (20.37)
	A. germinans	67 (26.17)	79 (30.86)	44 (17.19)	41 (16.02)	25 (9.76)	256 (59.26)
	L. racemosa	40 (45.45)	21 (23.87)	15 (17.05)	10 (11.36)	2 (2.27)	88 (20.37)
	Total	**122 (28.24)**	**121 (28.01)**	**94 (21.76)**	**66 (15.28)**	**29 (6.71)**	**432**

(b)	Mangrove taxa	Diameter class (cm)					Density (stumps ha^{-1})
		≤ 10.0	10.1-20.0	20.1-30.0	30.1-40.0	> 40.0	
Stumps	*Rhizophora* spp.	7 (2.39)	32 (10.92)	136 (46.42)	93 (31.74)	25 (8.53)	293 (100)
	Total	**7 (2.39)**	**32 (10.92)**	**136 (46.42)**	**93 (31.74)**	**25 (8.53)**	**293**
Trees	*Rhizophora* spp.	68 (10.64)	146 (22.85)	214 (33.49)	175 (27.39)	36 (5.63)	639 (100)
	Total	**68 (10.64)**	**146 (22.85)**	**214 (33.49)**	**175 (27.39)**	**36 (5.63)**	**639**

Values in parentheses indicate percentage of the total trees density per class per mangrove taxa, and the totals.

Based on the species' importance values, stumps of *Rhizophora* spp. were abundant in Mboussa Essengue followed by *A. germinans* and *L. racemosa* (Table 5.2 a). However, trees of *A. germinans* were more abundant than that of other sampled species (Table 5.2 a). In Bois de Singes, stumps and trees of *Rhizophora* spp. showed similar importance values (Table 5.2 b).

Although trunks usually harvested with chain-saw or machetes are often devoted for commercial and subsistence purposes, branches and cut stumps are left behind in the two sampling sites as woody debris. The overall above-ground volume of cut stumps with roots below-ground was 6,825.08 cm^3 ha^{-1}, out of which 66.59% were *Rhizophora*, 25.02% *A. germinans* and 8.39% *L. racemosa*.

The relationships established between the diameter at each measurement interval and D_{130} and uncut tree height are shown in Fig. 5.3. We have already mentioned above that the derived regression equations were employed to calculate the original structural parameters of stumps that were afterwards used to compute the C.I. Our results revealed that, for both sites investigated, the C.I. was higher prior to harvest than it was at the time of recording the data (Table 5.3).

Table 5.2 Importance Values (I.V.) of stumps and trees in the (a) Mboussa Essengue and (b) Bois de Singes mangrove forests (Douala, Cameroon).

(a)

	Mangrove taxa	Relative (%)			I.V	Rank
		Density	Frequency	Basal area		
Stumps	*Rhizophora* spp.	49.44	36.11	47.29	132.83	1
	A. germinans	36.96	33.33	44.33	114.63	2
	L. racemosa	13.60	30.56	8.38	52.53	3
Trees	*Rhizophora* spp.	20.45	20.70	23.06	64.19	3
	A. germinans	59.10	37.90	63.76	160.81	1
	L. racemosa	20.45	41.40	13.18	75.00	2

(b)

	Mangrove taxa	Relative (%)			I.V	Rank
		Density	Frequency	Basal area		
Stumps	*Rhizophora* spp.	100	100	100	300	1
Trees	*Rhizophora* spp.	100	100	100	300	1

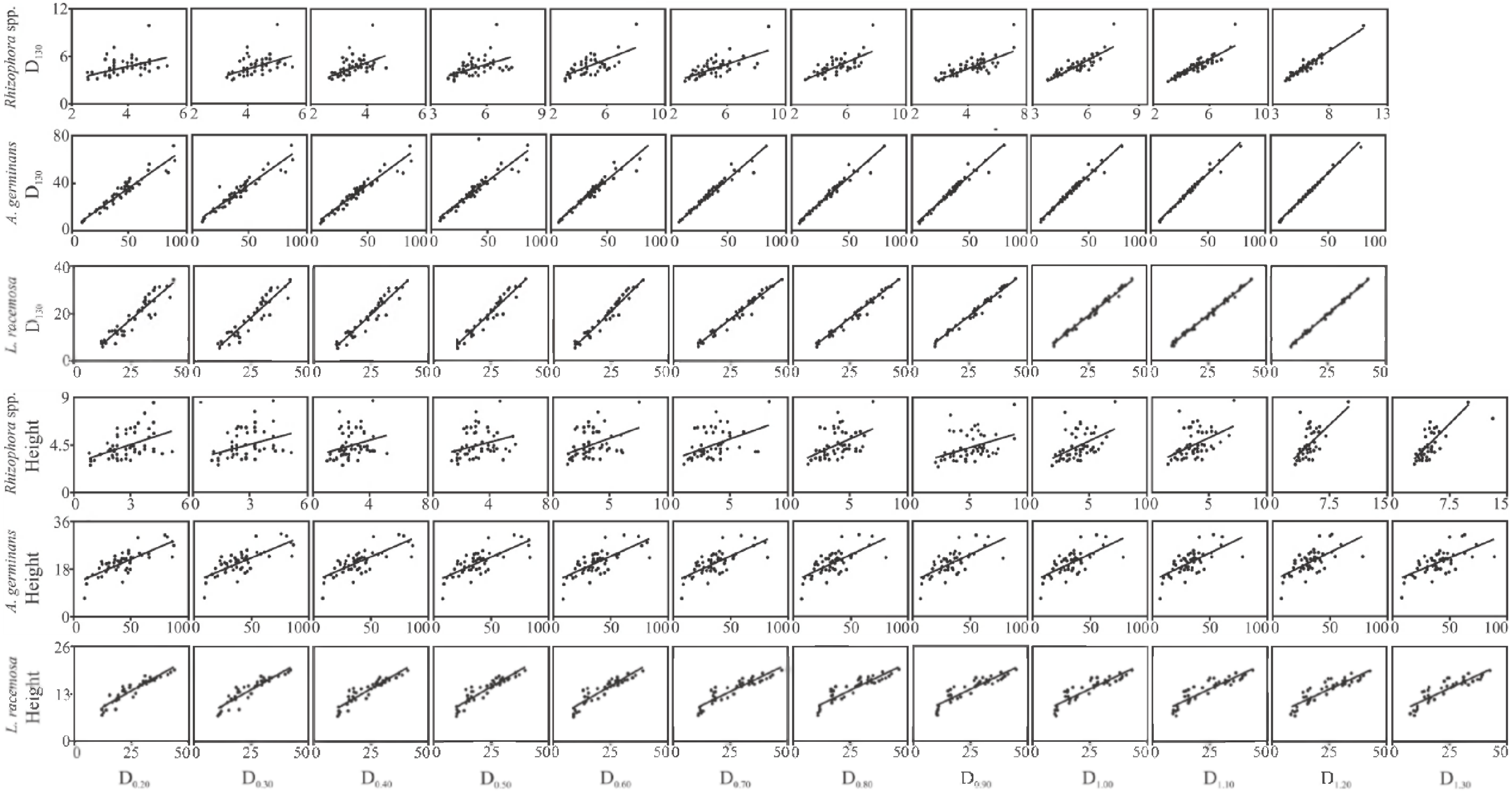

FIG. 5.3 Scattergrams of diameter at each measurement interval *versus* D_{130} (top) and uncut tree height. All the 69 allometric equations were significant ($p < 0.05$). The latter as well as the corresponding coefficient of determination are not labelled for clarity. Noted that because of the difference in species' architecture, the relationships are species-specific.

Table 5.3 Complexity index of the original (stumps and trees) and current (trees) of mangrove forests in Douala, Cameroon.

	Sites	Mboussa Essengue		Bois de Singes	
		Stumps and Trees	Trees	Stumps and Trees	Trees
1.	N° species	3	3	1	1
2.	Density ha^{-1}	1634	432	932	639
3.	Mean tree height (m)	12.16	14.05	12.21	14.77
4.	Basal area (m^2 ha^{-1})	34.9	17.87	49.33	35.25
5.	**Complexity index†**	**20.80**	**3.25**	**5.61**	**3.32**

N.B. Stumps height was converted to original tree height based on the significance of the allometric relationship between tree diameter and tree height. †The complexity index (C.I.) equals the product of (1), (2), (3) and (4) divided by 10^5.

5.3.2 *Trees and stumps distribution*

Stumps and trees of the three mangrove taxa were found in Mboussa Essengue whereas only stumps and stems of *Rhizophora* spp. were recorded along the belt transect in Bois de Singes. Although cut stumps of *Rhizophora* were widely distributed amongst sites, their stems were more or less common in the Bois de Singes and Mboussa Essengue stands, respectively.

5.3.2.1 Stump patterns

In the supra-littoral zone (plot 1) of Mboussa Essengue, 28 cut stumps (14, 10 and 4 stumps of *Rhizophora* spp, *A. germinans* and *L. racemosa*, respectively) were encountered. Likewise, in the mid-intertidal zone, corresponding to the interior of forest (plots 6-13), stumps were fairly uncommon compared to the high-intertidal zone (plots 2-5) of the forest (Fig. 5.4). We recorded in the mid-intertidal zone 192 stumps, of which 127 were *Rhizophora* spp., 39 *A. germinans* and 26 *L. racemosa*. In the high-intertidal zone, we sampled 404 stumps, out of which 168 were *Rhizophora* spp, 181 *A. germinans* and 55 *L. racemosa*.

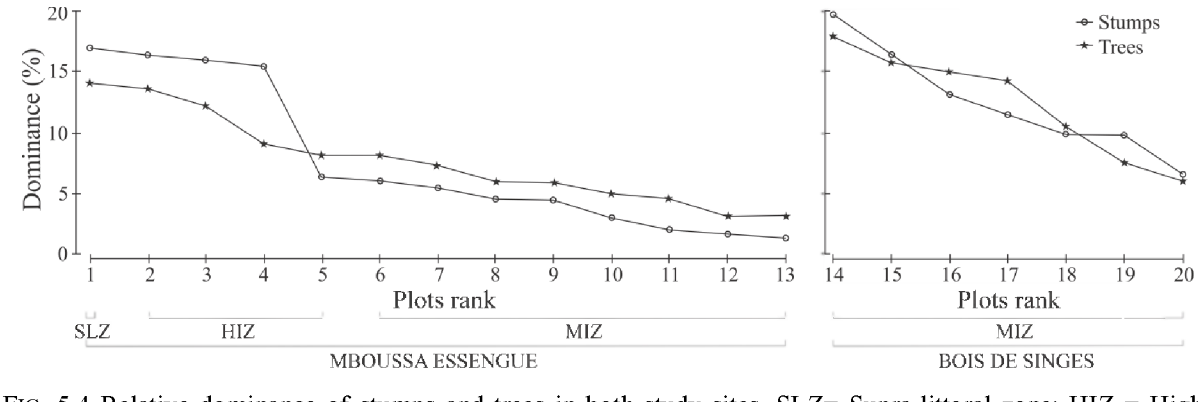

FIG. 5.4 Relative dominance of stumps and trees in both study sites. SLZ= Supra-littoral zone; HIZ = High-intertidal zone; MIZ = Mid-intertidal zone. The dominance is expressed as a percentage of the total abundance in each plot.

The most abundant stumps of *Rhizophora*, *L. racemosa* and *A. germinans* were recorded at plots 4 (60 stumps), 3 (20 stumps) and 5 (70 stumps), respectively. On the other hand, 82 stumps of *Rhizophora* spp. were found in the mid-intertidal zone of the Bois de Singes mangrove forest.

5.3.2.2 Trees configurations

Stems distribution in the Bois de Singes stand revealed that there were 179 trees of *Rhizophora* in the mid-intertidal zone. At Mboussa Essengue, trees of *A. germinans* were more common in the supra (11 trees), high (27 trees) and mid-intertidal (95 trees) zone of the mangrove forest, respectively. Besides that, there were 2, 13 and 31 trees of *L. racemosa* in the supra, high and mid-intertidal zone of Mboussa Essengue mangrove. *Rhizophora* trees were less frequent in the high-intertidal zone (2 trees) than in the mid-intertidal zone (44 trees).

5.3.3 *Spatial disturbance trends*

Both stand structures in Mboussa Essengue and Bois de Singes sampling sites faced anthropogenic disturbances. Stumps *versus* trees comparison curves, computed based on relative abundance of stumps and trees (Fig. 5.5), clearly display disturbance trends across the Mboussa Essengue site (W = -0.164) since the stump curve is almost above of the other (*i.e.*, that of the trees) (Fig. 5.5). In contrast, the slight separation of stump and tree curves in Bois de Singes (W = 0.002) denoted that this stand was less disrupted.

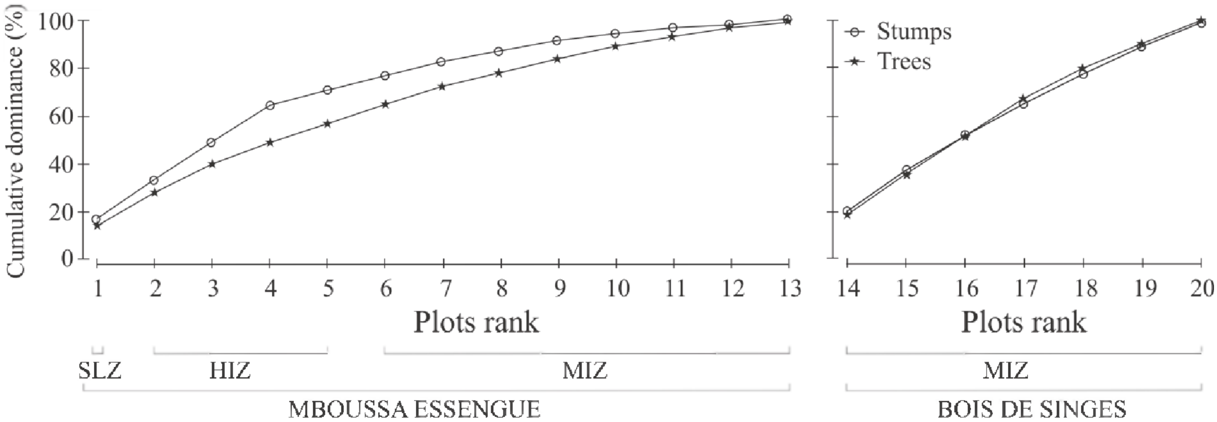

FIG. 5.5 *K*-dominance curves for stumps and trees indicating disturbance occurred across the sampling areas. These curves have to be interpreted as indicating large disturbance in Mboussa Essengue since the stump curve lies above the tree curve. In Bois de Singes, however, the fact that the two curves largely intersect denoted a 'less disturbance'.

5.3.4 *Simulation of the previous management scenarios*

Table 5.4 shows bias, accuracy, and modeling precision of each simulation scenario.

Table 5.4 Bias, accuracy and precision of the simulation results in comparison to the field data obtained in (a) Mboussa Essengue and (b) Bois de Singes.

(a)

Scenario	Bias	Precision	Accuracy
Without mortality	46.85	49.46	68.77
Natural mortality	8.04	15.09	17.17
Non-selective cutting 50%	14.73	16.99	22.68
Selective cutting of *A. germinans*	41.93	42.38	60.20
Selective cutting of *L. Racemosa*	32.85	34.73	48.25
Selective cutting of *Rhizophora* spp.	33.31	34.47	48.40
Cutting according stump diameter distribution	**0.0**	**9.49**	**9.49**

(b)

Scenario	Bias	Precision	Accuracy
Without mortality	11.23	23.05	25.74
Natural mortality	-19.04	18.00	26.48
Non-selective cut 50%	**-06.58**	**15.69**	**17.06**
Cutting according stump distribution	-0.03	17.32	17.33

Whereas the bias informs whether or not the simulation results systematically overestimate or underestimate the observed stem diameter distribution, the precision index is a measure of the deviation in each stem diameter size class. The index accuracy combines both the bias and the precision measure. Thus the scenario specified with the lowest value of accuracy resulted in a D_{130} distribution being most similar to the one observed in the field. For the study site Bois de Singes, a non-selective cutting of 50% of the trees is most plausible but there is no large difference to a cut according to the D_{130} distribution. The latter scenario is most plausible in order to explain the observed D_{130} distribution in Mboussa Essengue. The differences in these results are based on the shape of the D_{130} distributions observed in both sites (Fig. 5.6). A cut according to the size class distribution is more adequate for the Mboussa Essengue forest where the D_{130} distribution is strongly right skewed. The symmetry of the distribution observed in Bois de Singes levels the selectiveness of both scenarios out.

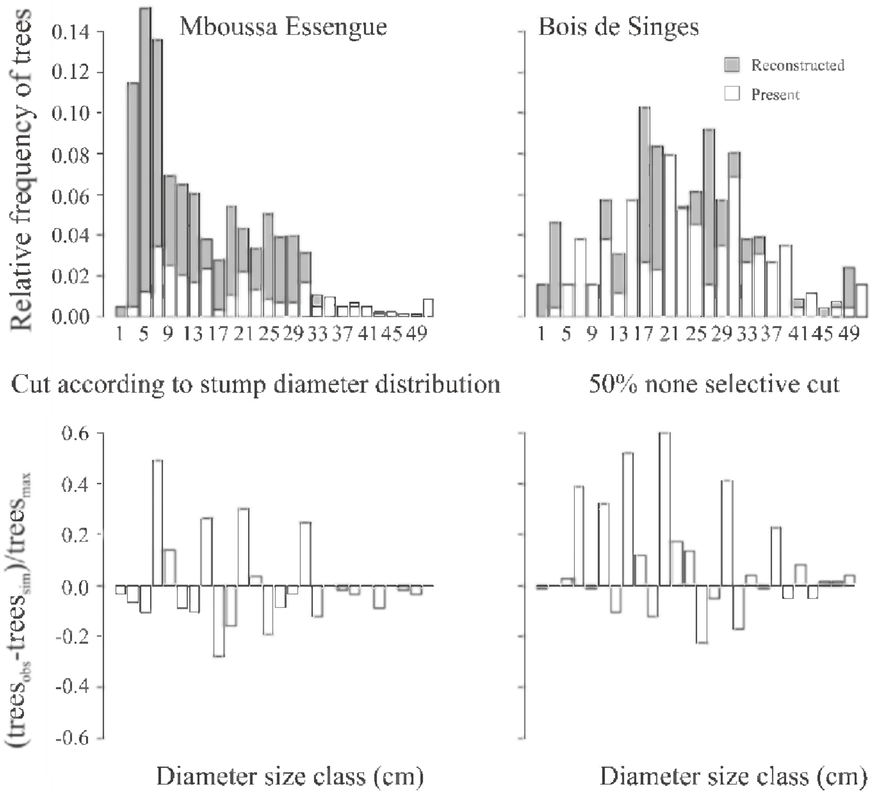

FIG. 5.6 Comparison of observed and simulated number of stumps and trees in both study sites. Whereas the D_{130} distribution observed in Bois de Singes is bell shaped and nearly symmetric (top right), the stem diameter distribution of the Mboussa Essengue forest is strongly right skewed. The overestimation balances the underestimation of size class frequency simulating the most plausible scenario to the Mboussa Essengue forest (bottom left). The most plausible scenario applied to the Bois de Singes results in an underestimation of the size class frequencies (bottom right). Hence the real cut intensity was lower than the one assumed in the simulations (50% cut of all trees).

5.4 DISCUSSION

5.4.1 *Vegetation structure*

Along the West coast of Africa, mangroves, though poor in plant species diversity, have large dense populated grown-up trees (UNEP 2007; Spalding *et al*., 2010). In Cameroon, these coastal ecosystems are subjected to considerable anthropogenic disturbances. In this study, for instance, we found that stump density (1495 stumps ha^{-1}) was higher than tree density (1074 trees ha^{-1}) along both belt transects, implying excessive wood harvesting in a peri-urban setting. Moreover, much stumps within plots were that of *Rhizophora* spp., which was expected since previous studies have reported that this species dominated the Cameroon coastlines (Van Campo & Bengo 2004; FAO 2007) and is very suitable for making charcoal or to be burned as fuelwood (Nfotabong Atheull *et al*., 2009). The variation in stump quantity between the two sites can be argued in the light of human pressure. The close proximity of human settlements to the Mboussa Essengue mangrove has facilitated a higher wood harvesting to meet subsistence needs for firewood and construction materials. This is consistent with findings of Ambastha *et al.* (2010) who found that the major disturbed mangrove forests in Bhitarkanika (Bhitarkanika Wildlife Sanctuary, India) were commonly located at ease access zones. Furthermore, perpetual land reclamation for the extension of the Douala seaport also showed consequences on the performance (Din *et al.*, 2008) and the structure of this mangrove forest.

In less accessible sites such as the Bois de Singes, there were more trees than stumps (see Table 5.1 a, b). The main anthropogenic disturbance that occurred within this mangrove forest remains sand and gravel extraction which were often carried out at low tide. During this activity, trees were often cut down only in the place of extraction sometimes located far from the channel. In this case, muddy sand or gravel is usually collected after digging large holes inside the mangrove forests (pers. obs.).

The higher C.I. of combined stumps and trees in Mboussa Essengue indicates that this peri-urban forest was structurally more complex (muti-species stand comprising large number of trees with low or medium size) before harvesting (Table 5.3). It is relevant to notice that the stump and tree density, species diversity and basal area contribute highly to forest complextity in Mboussa Essengue. This suggests that people usually harvest this type of dense mangrove forest. Likewise, the original mangrove forest in Bois de Singes was structurally more developed (single species stand mainly composed of large trees with stem diameter > 20 cm) (Table 5.3). Though both study sites face pressure by harvesting of trees, they remain more complex than those described by Cintrón & Schaeffer-Novelli (1983). In fact, riverine mangrove stands growing under equatorial climate (longer wet season, low salinity) often showed higher forest complexity (Blanco *et al.*, 2001).

The various changes in forest structure resulted from harvesting. The removal of trees can initiate a chain reaction of interrelated effects such as gap creation (Alongi & De Carvalho 2008). Most larger gaps found in the supra-littoral zone of the Mboussa Essengue mangrove forest, dominated by stumps, are surrounded by artificial dykes that have modified the drainage pattern. Forest harvesting may shift the climatic conditions that drive plant and microbial processes (Nave *et al.*, 2010). In our observation, stumps in the supra-littoral zone are intentionally uprooted to facilitate development of agriculture. This anthropogenic disturbance also has an important impact on mangrove forest structure and dynamics throughout the globe (Duke *et al.*, 2007). Except the plot 5, the supra and high-intertidal zone were more impacted than the mid-intertidal zone (Fig. 5.4). This could be due to the fact that people usually harvest wood from mangroves that are near to their homes (Walters 2005a). The presence of *Nypa fruticans* at the water edge and their seeds amongst gaps found in the mid-intertidal zone of the Mboussa Essengue mangrove forest suggests a recent change in forest structure.

Gap closure depends almost entirely upon the establishment and growth of new seedlings (Sherman *et al*., 2000). Compared to the mid-intertidal zone, the supra-littoral and high-intertidal zone of the Mboussa Essengue's mangrove forest are heavily exploited by local wood cutters. In this site, the size distribution of trees and stumps hints at a reduction in standing stock of smaller trees (≤ 10.0 cm) and lack of mature trees (> 40 cm) that could produce seedlings to replace them. Similar patterns have been found in others mangrove forests logged selectively, or on a small-scale, or both (Walters 2005a; López-Hoffman *et al*., 2006). The mid-intertidal zone of mangrove in Bois de Singes is less intensively harvested. In addition to sand and gravel extraction, this forest often faces different threats such as industrial discharge and various organic by-products and sand-pits (FAO 2007). Although cut stumps and trees of *A. germinans* and *L. racemosa* were not recorded within the Bois de Singes plots (14-20), trees of *A. germinans* were observed at a distance of 50 m outside the plot area (pers. obs.). The fact that logging is less accented in the mid-intertidal zone of both study sites is not the result of management effect, but is mostly related to the high soil instability (mid-intertidal zone) that prevents wood removal by people.

Notwithstanding the abundance of *Rhizophora* in the Cameroon estuary (UNEP 2007), their propagule dispersal seems to be compromised in Mboussa Essengue where dykes prevent frequent bi-daily tide flooding. Besides this, significant anthropogenic pressure should probably result in losses of less abundant species such as *L. racemosa*.

The above-ground volume of stumps with roots below-ground is given in the result section. Taking into account that between 0.20 and 1.30 m above-ground, the diameter of *A. germinans* and *L. racemosa* increases with height whereas that of *Rhizophora* decreases, we therefore acknowledge that the cut stumps volume (left behind in the forest) of both former species have been underestimated and that of the latter species overestimated. Furthermore, when taking into account the fact that branches and cut stumps remnants can be used for livelihood purposes, we assume that this phenomenon constitute an important loss.

5.4.2 *Simulation experiments related to anthropogenic activities*

In order to identify the human wood cutting activities being most plausible in both studies sites, simulation experiments were carried out with the mangrove simulation model KiWi (see Berger *et al*., 2008 for details). The results revealed that a tree cut non-selectively with respect to the size class distribution is most plausible for the Bois de Singes. However, logging according to the size class distribution leads to similar results. The similarity of both scenarios can be explained by the symmetry in the forest structure levelling the selectiveness of both scenarios out. In contrast, the skewness of the D_{130} size class distribution in Mboussa Essengue is reflected in the cutting activities. Trees belonging to the most frequent size classes are more often harvested than others. Although similar findings have been reported in the Philippine (Walters 2005a), this is not an evidence since logging activities in Kenya (Dahdouh-Guebas *et al.*, 2000a; Kairo *et al.*, 2002) and in the others zones of the Cameroon estuary (Din *et al.*, 2008) proved cutters to go for the larger diameter, tall and straight stems.

It should be noted that the simulation results can only be considered in a qualitative sense: (1) the KiWi model could not be parameterized for the study sites based on the available data but uses the growth parameters validated for our mangrove species but growing in the Neotropics. The shortness of the simulation period (6 years) reduces, however, the uncertainties produced by the growth parameters; (2) the spatial coordinates (x, y) of the trees measured in field were not available. The positions of the trees initialized in the simulated forest were thus chosen randomly based on field knowledge. Since the KiWi model considers the local neighbourhood situation in order to calculate tree-to-tree competition, this lack of information affects the calculation of the annual D_{130} increments. Assuming that self-thinning could have led to a more equal distribution in the real forest, the growth increment could be underestimated and the resulting natural mortality could be overestimated in the simulated forest.

5.5 CONCLUSION

We reconstructed past structural complexity of the current disturbed mangrove forest based on stumps structural parameters. In addition, by means of the mangrove forest simulation model KiWi, we simulated the previous stand structure and select the most plausible cutting option which could have produced the current forest structure in Mboussa Essengue and Bois de Singes. Both methods revealed similar findings. For instance, we recorded that people usually harvested most frequent mangrove trees growing in the Mboussa Essengue site. Whereas in Bois de Singes, we found a non-selective cutting levelling logging according to stump diameter distribution. The removal of trees has significant impact on mangrove structure and dynamic. We determined that variation amongst harvest impacts was best explained by variation in stand location. The Mboussa Essengue mangrove forest, located close to human settlements was more disturbed. Here, the reduction in standing stock of smaller trees ($\leq$ 10.0 cm) combined with the presence of artificial dykes (supra-littoral zone) and the scarcity of mature trees (high-intertidal zone) that could produce new seedlings probably have a greater disturbance on the mangrove rejuvenation. Like the mid-intertidal zone of the Mboussa Essengue's mangrove forest, the less accessible mangrove of Bois de Singes (also located in the mid-intertidal zone) was not intensively harvested. Despite the aforementioned anthropogenic impacts, these mangrove forests still have the potential to self-regenerate, especially in zones where anthropogenic alterations of microtopography (dyke establishment, wood and stump removal, housing, agriculture, sand-pits) are uncommon.

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PLANCHE 6. Une image QuickBird (Google Earth™, 2001) montrant la structure de la végétation des mangroves dans une zone non périurbaine située dans l'estuaire du Cameroun (3°57'N - 9°38'E).

PLATE 6. QuickBird image (Google Earth™, 2001) showing mangrove vegetation structure in a non peri-urban setting of the Cameroon estuary (3°57'N - 9°38'E).

CHAPTER 6

MAPPING MANGROVE DIAMETER, BIOMASS AND CARBON STOCK IN CAMEROON ESTUARY: AN APPROACH USING PARAMETER INVERSION FROM SATELLITE IMAGE TEXTURE

ADOLPHE NFOTABONG ATHEULL[1,2], NDONGO DIN[2], NICOLAS BARBIER[1,3] AND FARID DAHDOUH-GUEBAS[1,4]

[1]Laboratory of Systems Ecology and Resource Management, c/o Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles – ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium.
[2]The University of Douala, Faculty of Science, Department of Botany, P.O. Box 8948 Douala, Cameroon.
[3]IRD, UMR botAnique et bioinforMatique de l'Architecture des Plantes (AMAP), Boulevard de la Lironde, TA A-51/PS2, 34398 Montpellier Cedex 05, France
[4]Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussels, Pleinlaan 2, B-1050 Brussel - VUB, Belgium.

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ABSTRACT

In the current context of climate change, along with the sea level rise, mapping coastal vegetation such as mangroves constitute an important topic. In equatorial regions, mangroves are well-developed and have biomass over 450 t of dry matter (DM) per hectare. Several efforts have been made to map the structural and functional parameters of mangrove forests. But, they solely focused on mapping leaf area index (LAI), tree height and biomass distribution. In this contribution, we have used parameter inversion from satellite image (VHR QuickBird data) texture (performed via Fourier Transform Textural Ordination (FOTO) method) to produce a landscape scale map of mangrove tree diameter and carbon stocks in the Cameroon estuary. Moreover, in agreement with previous publications, we used the same methodological approach to map the mangrove canopy and standing biomass. The resulting map clearly depicted canopy heterogeneity across the mangrove ecosystem. These different patterns represented the areas covered by medium and high stature forests. The trends in landscape features, instead of being the result of human-induced disturbances or different soil characteristics, are mostly related to the past history of the studied forests. Comparison between the FOTO-inverted and ground truth data revealed that mean tree diameter and biomass had a bias of about -0.007 cm and 1.06 t DM ha^{-1}, respectively. The estimates indicate that most of the standing biomass (100-200 t DM ha^{-1}) resides in medium-stature mangrove stands (7-14 cm). Above ground C storage shows two well-defined peaks around values of 100 t ha^{-1} and 200 t ha^{-1}. With regard to the REDD (reduction of carbon emissions due to deforestation and forest degradation) policies, these findings would serve local policy-makers to monitor and manage mangrove forests. Interestingly, they are in a straight line with the interesting prospect of recording several regional databases featuring field-measured forest parameters and corresponding forest canopy images.

Keywords: Remote sensing, Fast Fourier transform, Canopy texture, Mangrove diameter, Biomass, Carbon sequestration, Cameroon estuary

6.1 INTRODUCTION

Mangroves are salt tolerant trees located in the harsh interface between tropical lands and seas. Although these coastal forests are architecturally simple and usually harbour few tree species, they reduce the impact of waves, storm surges, tsunami and hurricane on the coastlines (Dahdouh-Guebas & Koedam 2006a; Luong and Massel 2008; Mukherjee *et al.*, 2010). Mangrove ecosystems are highly productive and play a key role in maintaining and shaping the unique habitat as a nursery for fish and shelfish species (Nagelkerken *et al.*, 2008; Luo *et al.*, 2010). Tree size as well as the standing biomass and carbon storage of mangrove forests is immense, especially in equatorial regions, thus competing with the biomass of many tropical rainforests (Alongi 2009, 2011; Donato *et al.*, 2011; Kauffman *et al.*, 2011; Mitra *et al.*, 2011). Recent estimation indicated that the total above-ground biomass of the World's mangrove forests may be over 3700 Tg of carbon (Spalding *et al.*, 2010). Thus, mangroves can contribute in the reduction of atmospheric CO_2 concentrations and accordingly mitigate the negative effects of the global surface warming. Notwithstanding their great ecological importance, mangroves are critically endangered or approaching extinction in 26 out of the 120 countries where they occur (Duke *et al.*, 2007; FAO 2007). The main causes related to this damage include over-harvesting, conversion to aquaculture, agriculture and anarchic urbanization. Under such disrupted conditions, one approach to assess forest structure dynamics is through spatially extensive field surveys. Although these types of investigations provide accurate data on diameter distributions, the nature of the mangrove environment (soft substrate, tide duration, prop roots complexity) renders these methods difficult to implement in larger extents.

The use of remote sensing techniques combined with field measurements to detect and monitor mangrove loss has advanced rapidly in recent years (Dahdouh-Guebas *et al.*, 2000b; Krause *et al.*, 2004; Satapathy *et al.*, 2007; Everitt *et al.*, 2010). However, studies that attempt to estimate structural properties related to mangrove tree diameter at the landscape level are lacking, although the latter parameter is a good indicator of forest biomass (Fromard *et al.*, 1998; Sherman *et al.*, 2003) and carbon storage. Though SRTM (*Shuttle Radar Topography Mission*) elevation data have been found useful in mapping spatial distribution of mangrove tree height and standing biomass in some areas (Li *et al.*, 2007; Simard *et al.*, 2006, 2008; Fatoyinbo *et al.*, 2008), they are unable to represent the whole range of structural aspects observable in well-developed tropical forests (Proisy *et al.*, 2000) since the radar-derived intensity penetrates only a few meters into the canopy. Similarly, Synthetic Aperture Radar (SAR) data allowed an estimation of forest structural parameters, but the P-band signal often saturates in mangrove stands of biomass greater than 160 Mg ha^{-1} (Mougin *et al.*, 1999). Likewise, satellite images obtained from the sensors like Landsat TM and ETM+, SPOT (2 and 4), MODIS, IRS, ASTER (De Wasseige & Defourny 2002; Huete *et al*., 2002; Lu *et al*., 2004) provide useful insights into vegetation structure but are usually limited by their low spectral and spatial resolutions.

Very High Resolution (VHR) air-borne (Couteron *et al*., 2005, 2006; Zhang 2008) and space-borne imagery (Proisy *et al*., 2007; Barbier *et al*., 2010, 2011) were found more appropriated to characterize the forest structure and dynamics, but their acquisition costs are still high. Such aforesaid limitations may be overcome by using freely available Google Earth® images which do provide sufficient information to derive textural properties of tropical forests (Barbier *et al*., 2010). A recent report (Proisy *et al*., 2007) suggests that the development of a standardized measurement for forest canopy grain with broad regional validity would be a realistic goal in the future. Of course, additional research works involving others kind of VHR images (*e.g*., IKONOS, QuickBird and GoeEye-1) and supplement field-measured forest parameters could help to achieve such objective. Likewise, sophisticated models allowing computation of biomass and carbon stocks (Chave *et al*., 2005; Soares *et al*., 2005; Komiyama *et al*., 2005, 2008; Kauffman *et al*., 2011) or simulation of tree diameter growth (Chen & Twilley 1998) and neighbourhood competition (Berger & Hildenbrandt 2000; Berger *et al*., 2006) are also quite useful, especially in case of existing time gap between ground and remote sensed data.

Canopy textural indices derived from the Fourier-based Textural Ordination (FOTO) method can be strongly correlated with the forest structural (diameter) and functional (biomass and carbon stocks) parameters (see Couteron *et al*., 2006; Proisy *et al*., 2007; Barbier *et al*., 2010) and therefore used to infer maps of inverted parameters. These data can be greatly useful to assess the significance of mangrove forest as carbon sinks since the maps built are able to provide sufficient information about the spatial distribution of mangrove tree diameter, biomass and carbon reserve at the landscape scale. Moreover, the only practicable approach for monitoring deforestation at a national level is through interpretation of such remotely sensed data (DeFries *et al*., 2007). In order to contribute in the building of standardized texture indices and provide sufficient information that can serve local policy-makers in monitoring present and ongoing anthropogenic disturbances on mangrove vegetation structure, we applied the FOTO method to VHR QuickBird images (~1 m resolution) of the Cameroon estuary. Our objective was to build a baseline map to quantitatively estimate the diameter distribution, standing biomass and carbon stocks of the mangrove forest dominated by the genus *Rhizophora*. By doing, we also contributed in the building of 'meta' FOTO data very useful to calibrate standard strong relationships between textural indices and forest parameters (see Proisy *et al*., 2007).

6.2 MATERIAL AND METHODS

6.2.1 *Study area*

The study site located in the Cameroon estuary (3°40'-4°11'N and 9°16'-9°52'E) covers 2260 ha (Fig. 6.1).

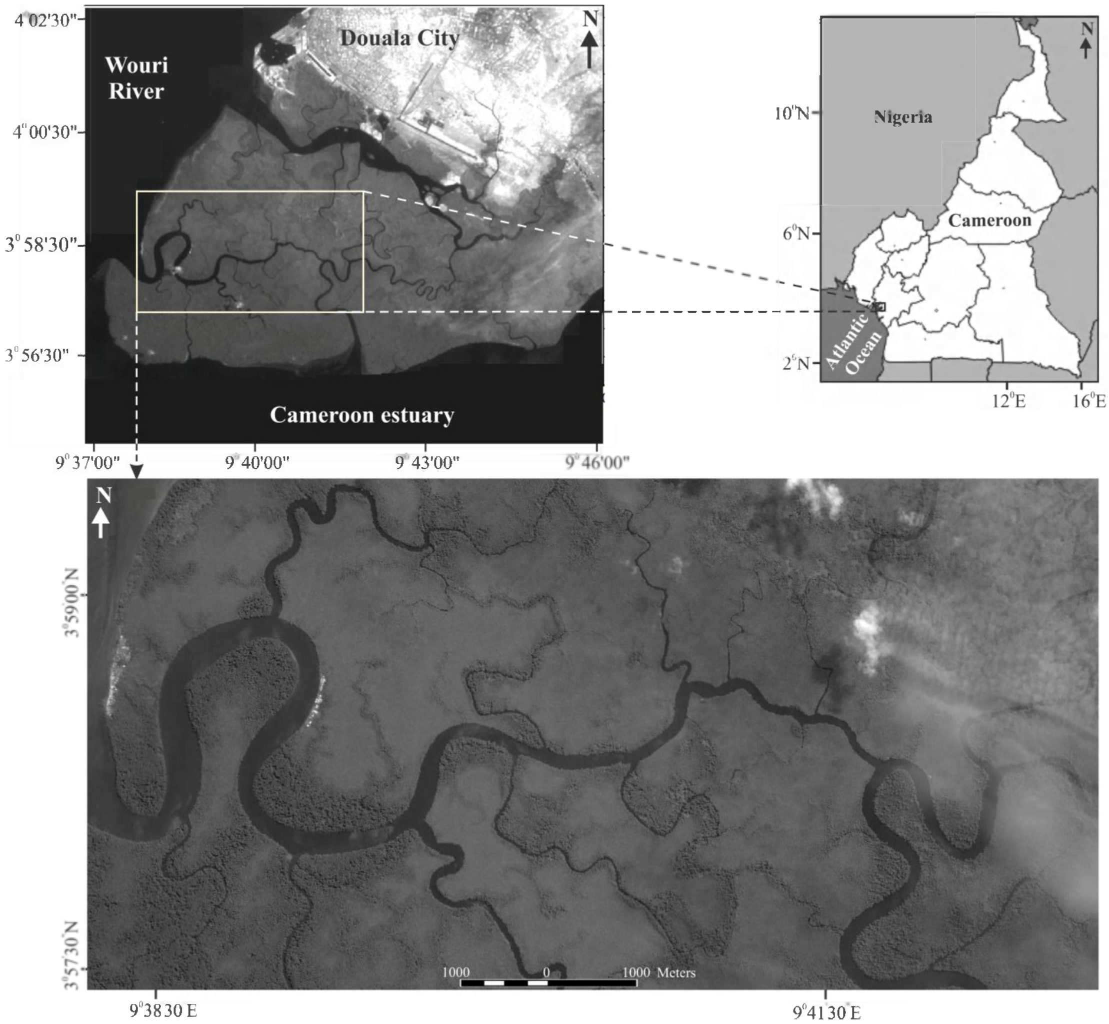

FIG. 6.1 Map showing the location of the studied mangrove forest in the Cameroon estuary.

The estuarine complex receives freshwater through the Mungo, Dibamba and Wouri Rivers which cross the mangrove system. The mean tidal amplitude is about 1.65 m. Climate is equatorial, with a 9 wet-months season. Cloud is frequent in this estuarine area. The relatively weak winds all year round along with the absence of storm surge, cyclone or tsunami result in the lack of mangrove damage from natural hazards. In this coastal ecosystem, five true mangrove species are widely distributed, namely *Rhizophora racemosa* Meyer, *R. mangle* L., *R. harrisonii* Leechman, *Avicennia germinans* (L.) Stearn and *Laguncularia racemosa* (L.) Gaertn. f. (nomenclature according to Tomlinson 1986). Amongst them, only trees of the genus *Rhizophora* are found growing in our study area. Here, the variation in plants growth is common (Spalding *et al.*, 2010). Trees of *R. mangle* and *R.*

harrisonii rarely grow up to 7 m height (in harsh environment) whereas *R. racemosa* can exceed 40 m (Saenger & Bellan 1995). This difference in stands structural development often led to contrasted textural aspects of the mangrove forest canopy.

6.2.2 *Tree census*

Field measurements were carried out from June to July 2009. The sampling area was selected based on the availability of cloud free VHR QuickBird images (May 2001). The period of field data collection was different to that of the image acquisition. Thus, considering the 8 years time gap between the acquisition of satellite images and the fieldwork expedition, and in order to ignore new pioneering stands during the images processing, sampling areas were not located at a distance less than 5 m to the water line.

Across the less disturbed mangrove stands, we established 7, 7 and 6 plots in low (height < 8 m), medium (9 m ≤ height ≤ 15 m) and high (up to 15 m height) stature forests dominated by *Rhizophora*, respectively. A plot dimension was set to 20 m × 20 m. In each plot, we identified the species and measured the diameter (at breast height or 30 cm above the uppermost intersection of the prop roots for *Rhizophora* when intersections where up to 1.30 m) using a measuring tape. Then, we measured the height of dwarf trees in the low-stature zones using a 'pre-marked bamboo'. However, this method could not be applied in some plots where the vegetation consisted mainly of trees up to 9 m height. In such cases, we used a clinometer to measure the tree height. Finally, we used a hand held GPS (Global Positioning System) (Garmin etrex Vista HCx GPS) to locate the sample plots.

6.2.3 *Sediment sampling*

Soil type can influence plant growth and accordingly the spatial trend in textural aspects of the mangrove canopy. With respect to this hypothesis, soil cores were collected in the plots at low tide using an Eijkelkamp gouge auger. After collection, a Portable Multiparameter Multi 3410-WTW was used to measure the water conductivity and pH in the hole. Muddy sediments were first air-dried for 2 weeks and afterwards redried at 105°C for 120 h in an oven. These sediments were ground to a fine powder using a FRITSCH planetary crusher. Their total carbon and nitrogen were determined by combustion at 1100°C with a LECO Truspec® apparatus. C/N values were obtained directly by calculating the atomic ratio of carbon *versus* nitrogen concentration measured with the LECO analyzer. Analysis of organic matter content was made using the calcimetry method. The percentage compositions of sand, silts (fine and coarse) and clay in the sediment samples were determined by the method of Krumbein & Pettijohn (1938), that combines sieving and pipetting.

6.2.4 *Diameter and biomass adjustment*

Taking into account the progressive yearly increment of stem diameter and height during the aforesaid time gap, we judged relevant to adjust the structural parameters recorded during our sampling campaign. Regarding the diameter adjustment, the FORMAN model (Chen & Twilley, 1998; also see Berger *et al.*, 2006; Proisy *et al.*, 2007) was found appropriated. This model assumes that the growth equation for a tree under optimal conditions is as follows:

$$\frac{d[D_{130}]}{dt} = \left[\frac{GD_{130}.(1 - D_{130}.H / D_{130max}.H_{max})}{274 + 3b_2.D_{130} - 4b_3.D_{130}^{\;2}}\right]$$

where D_{130} is the diameter at breast height (cm), H is the tree height (cm), D_{130max} and H_{max} are the maximum values of diameters and heights for a given tree species. G, b_2 and b_3 are species-specific parameters (see Chen & Twilley 1998). Since mangrove structural parameters differ according to the biogeographic regions (Spalding *et al.*, 2010), it is often advocated to use local values of D_{130max} and H_{max} in the calculation of the adjusted D_{130}. In the Cameroon estuary, these values are relatively similar for the two species of *Rhizophora* (*R. racemosa* and *R. harrisonii*) when they settled under optimal conditions. Accordingly, the D_{130max} and H_{max} were set to 95 cm and 40 m, respectively.

Moreover, plot biomass adjustment was performed by applying a common allometric equation of Komiyama *et al.* (2005). This exponential model (*e.i.*, $W_{top} = 0.251pD_{130}^{\;2.46}$) is considered to be highly species-specific (*i.e.*, wood density (p) of the species constitutes an important determinant) but less site-specific. For this reason, we found relevant to measure the wood density of *Rhizophora* in our sampling area. The adjusted plot biomass values were converted to carbon stocks using the method from 2006 IPCC GL-AFOLU, that is $C_{top} = 0.47 \times W_{top}$ (see also Donato *et al.*, 2011 (supplementary information)).

6.2.5 *Image processing*

Vertical aerial canopy images were extracted from Google Earth Pro® interface at a metric resolution (~1 m). These orthorectified images from 2001 consist of true colour composites of blue (0.45-0.52 µm), green (0.51-0.60 µm) and red (0.63-0.70 µm) bands. We did not make radiometric or geometric transformations. Images were imported into ArcGIS 9.3, assembled in mosaic and geo-referenced to UTM Zone 32N WGS 84 projection using a topographic map obtained from the Cameroon National Center of Cartography. The root mean square (rms) errors was under 2 m. Visual delineation of cloud, settlements, water bodies and shadows was performed in order to mask them before texture analysis (Fig. 6.2, step 1). The workable mangrove areas extracted were exported from ArcGIS 9.3 to Matlab®

(MathWorks, Inc.) interface in order to run the Fourier transform textural ordination analysis.

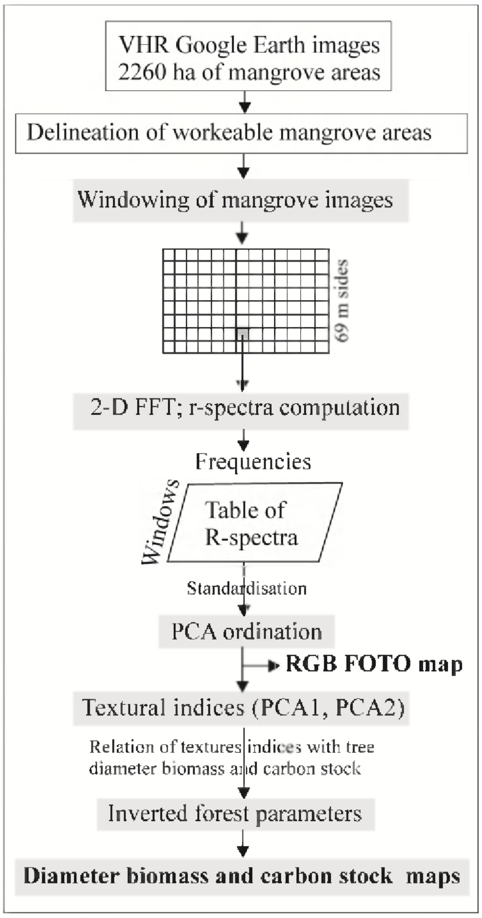

FIG. 6.2 Flow chart of the FOTO method applied on VHR QuickBird images for mapping mangrove diameter, biomass and carbon stocks (adapted from Proisy *et al*., 2007; Barbier *et al*., 2010).

6.2.6 *FOTO method*

Detailed presentation of the FOTO method as well as its application for processing digitized aerial photographs (Couteron 2002; Couteron *et al*., 2005, 2006), Ikonos (Proisy *et al*., 2007) and QuickBird (Barbier *et al*., 2010) images have been recently published. Therefore, only broad outlines of this method are provided here. In this study, we present the second application of the FOTO method to VHR images of mangroves.

The textural analysis starts by partitioning the canopy images in square windows (windowing of the images). The window size was chosen to include at least three repetitions of the sampling plot area. In our case, the dimension of plot side was 20 m, and window size was therefore set to 69 m (69-pixel windows). This window size remains within reasonable boundary range, that is 30 m to 100 m for VHR panchromatic data (Proisy *et al*., 2007).

Each square window is characterized by its Fourier radial spectrum (r-spectrum) obtained by subjecting the window to the two-dimensional discrete Fast Fourier Transform (FFT), computing the periodogram (squared amplitude) and averaging the latter across directions

(Fig. 6.2). R-spectra depict the partition of image gray level variance between frequency (scale) bins. A high value at low frequency indicates that the window contains large objects, whereas high frequency contributions describe the fine grained textures. A table of the r-spectra corresponding to r-spectrum values obtained for a set of spatial frequencies (columns) and individual windows (rows) was built. The standardized r-spectra were ordinated using principal component analysis (PCA) (that is eigenvector analysis of the correlation matrix between spatial frequencies) and classified using *k*-means clustering Euclidean distance. These multivariate analyses allowed the identification of the main gradients of textural variation between windows, clearly separating canopies dominated by small vs. large trees. Such PCA axes obtained from the FOTO analysis have been shown to be non-saturating estimates of mangrove biomass and crown size distribution, as well as allometrically of other stand parameters.

6.2.7 *Parameter inversion from image texture*

The most prominent principal component axis (PCA1) related to the gradient of mean crown sizes. Taking into account the allometric constraints in trees and stands (Chave *et al.*, 2005), good relationships can be established between the PCA1 and forest parameters such as stand density, mean quadratic diameter, biomass (Couteron *et al.*, 2005; Proisy *et al.*, 2007; Barbier *et al.*, 2010) and carbon stocks. To check the strength of this correlation, the textural indices that correspond to each sampled plot were extracted and plotted against the adjusted field-measured structural (mean quadratic diameter and height) and functional (average quadratic biomass and carbon stocks) parameters. The coefficient of determination of the resultant simple regression model, which is of the form $y = ax + b$, was evaluated. Whenever the model was significant, the structural and functional parameters were inverted and computed based on the regional map of mean crown textural indices. Finally, a well-matching between the FOTO-inverted (derived from PCA1) and sampled mean quadratic diameter and biomass should be checked by calculating the potential bias and rms errors.

6.3 RESULTS

6.3.1 *Textural ordination of the mangrove canopy*

Textural ordination of the Cameroon’s mangrove canopy yielded most meaningful results that could be noticed from the two first factorial planes of the PCA (Fig. 6.3 A, B). The first axis explained about 70.6% of the total variability observed in r-spectra, while the second axis accounted only for 13.3% (Fig. 6.3 A). The spatial frequencies are considered as the number of repetitions of the template periodic pattern on a 100 m reference distance. The correlation circle shown in Fig. 6.3 B clearly illustrates which type of spatial frequencies (expressed in cycles hm^{-1}) characterized each of the two main PCA axes.

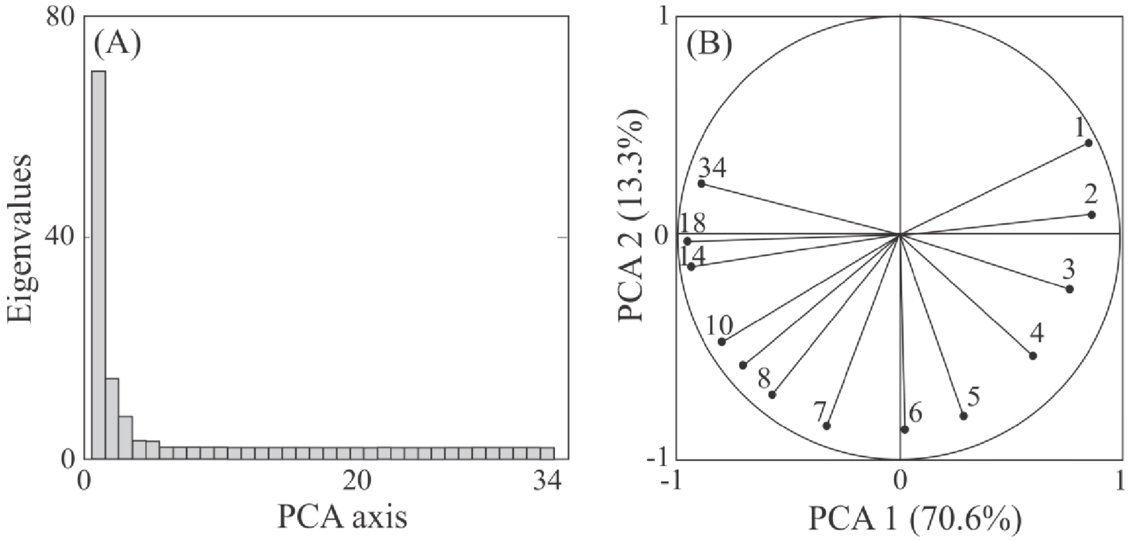

FIG. 6.3 (A) Eigenvalues (% of total variance) of the axes yielded by the Principal Component Analysis (PCA) of the spectra table. (B) Correlation between PCA axes and spatial frequencies (in cycles hm^{-1}). Each radial direction in the PCA plane corresponds to the relative importance in the spectrum of particular ranges of spatial frequencies (wavenumbers). Some of the wavenumbers above 8 are not labeled to incre ase legibility of the figure.

A noteworthy opposition between small (1-4 cycles hm^{-1}, 50 m $\geq \lambda \geq$ 25 m) and large frequencies (10-34 cycles hm^{-1}, 10 m $\geq \lambda \geq$ 2.94 m) were found along the first PCA axis, while intermediates spatial frequencies (5-9 cycles hm^{-1}, 20 m $\geq \lambda \geq$ 11.11 m) were correlated with negative PCA2 values. Therefore, windows with coarse grained canopy textures were clustered on the positive extremity of axis 1, while fined-grained canopy aspects were grouped on the negative extremity of the same axis (Fig 6.3 B). Windows of intermediate textures were mostly located below the axis origin, along with the negative side of axis 2. The variability between radial distances from the PCA origin indicated relative dominance by two length scales and therefore implied heterogeneity of spatial structure in the image.

6.3.2 *Classification of mangrove cover spatial patterns*

To ease understanding, a classification (*k*-means clustering) of r-spectra was applied after standardization (*i.e.*, column-wise subtraction of the mean and division by the standard deviation) of the table containing the radial spectra of all analysed unit windows. This clustering algorithm classifies windows on the basis of their close resemblance (minimizing the within-cluster variance of Euclidian distances) with respect to coarseness or fineness of the canopy texture. The result yielded a cloud of points with obvious delimitation indicating four distinct groups which are illustrated in the two first PCA planes by different grayscale levels (Fig. 6.4).

Group A displayed windows with fine-grained texture that were characterized by a regular spatial configuration of 'close-fitting' tree crowns. These patterns related to mixed medium-stature stands dominated by trees of *R. racemosa* and *R. harrisonii*. Under such dense vegetated areas, the mangrove associated species such as *Acrostichum aureum* L. was sometimes found. This group gathered mean standardized r-spectrum (*i.e.*, proportion of variance in image grayscale levels) dominated by very high spatial frequencies (> 20 cycles hm^{-1}) (Fig. 6.5 A).

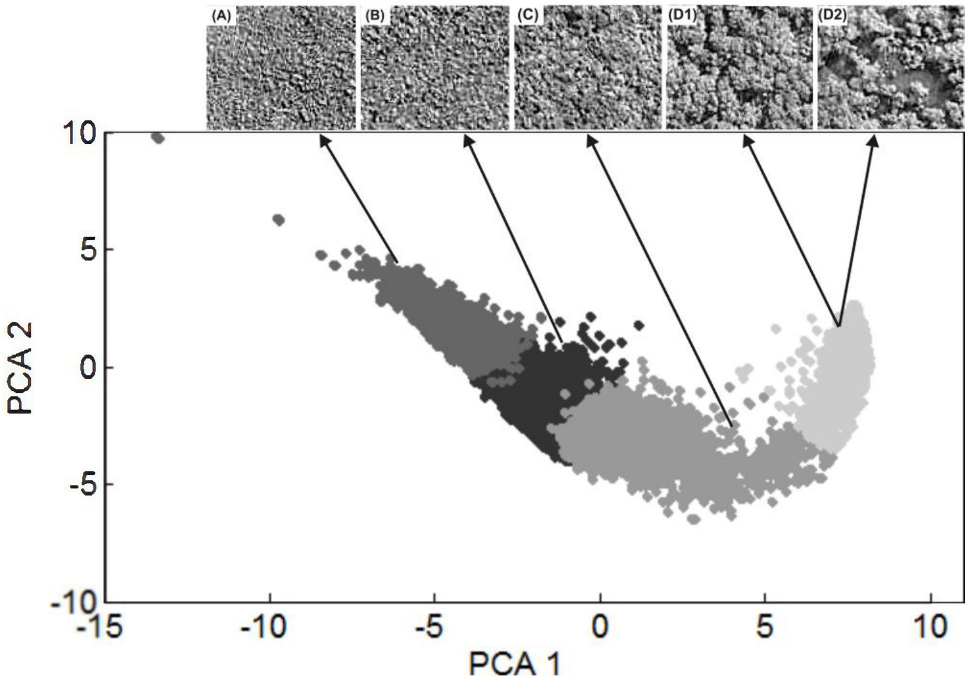

FIG. 6.4 PCA summarizing the variations in mangrove canopy grain identified by *k*-means clustering of windows scores. Each point corresponds to a single 69 m side unit window and is characterized by its Fourier r-spectrum. Different canopy textures representing each of the four coarseness groups are also illustrated.

Group B and C showed windows characterized by intermediate textures (mixed stands sometimes made of low, medium and high-stature trees of *Rhizophora racemosa* and *R. harrisonii*). Tree height in the latter group was slightly higher compared to that of the former group (Fig. 6.4). With respect to field observations, windows clustered in group C were often close to minor creeks located away from the major water channels. Group B had a mean standardized r-spectrum that increased for spatial frequencies in the range 5-9 cycles hm^{-1}. Whereas in group C, the proportion of variance in image grayscale levels showed a maximum value (~1.6) for spatial frequencies around 7 cycles hm^{-1} (Fig. 6.5 C) (*i.e.*, those corresponding to the wavelength of the intermediate textures (*e.g.*, 14.28 m)). Group D was marked by the presence of well-developed trees (high-stature forests) densely (D1) or sparsely (D2) distributed (coarse heterogeneity) in the vicinity of the major channels. This group had relative similar strong peak value (~1.7), though, in small spatial frequencies (< 5 cycles hm^{-1}) (Fig. 6.5). Unit windows of Group D2 were characterized by the presence of sparse grown-up trees of *Rhizophora racemosa* (light-grey) that were punctuated by large gap patches (dark areas). Such artificial gaps have circular or elliptical shapes and contained the remaining stems and branches of cut trees.

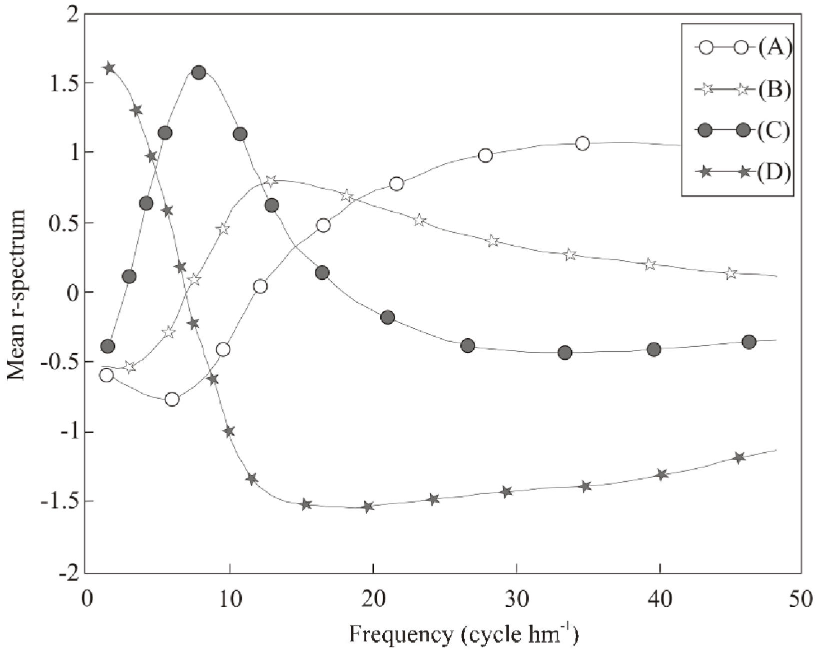

FIG. 6.5 Mean r-spectra of each of the four k-means groups displayed in the above PCA planes.

6.3.3 *Mapping textural gradients*

Although the proportion of the total variance explained by the third PCA axis was low (~5.8% of the total variance), we have computed window scores against the three first PCA axes as RGB values. The derived RGB FOTO map showed obvious trends in canopy textural properties across the mangrove ecosystem (Fig. 6.6).

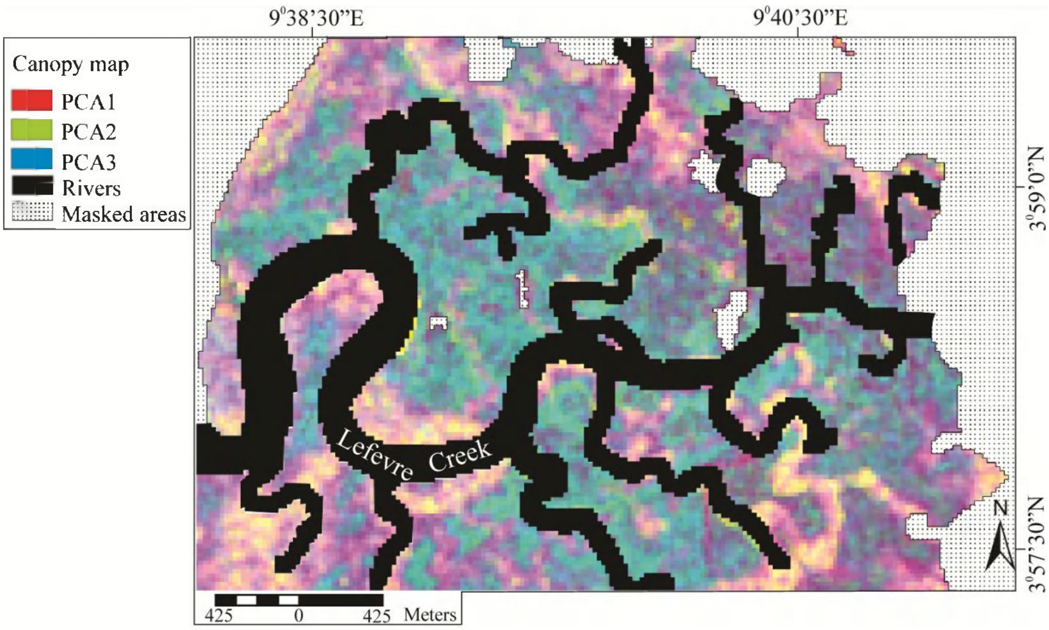

FIG. 6.6 FOTO map of the mangrove canopy texture in the Cameroun estuary.

The left masked area represented the main water channel of the Wouri River and the remaining dotted polygons corresponded to the zones covered by clouds or shadows. The spatial pattern of mangrove trees revealed a remarkable zonation (perpendicular to the network of tidal channels) of texture types which was clearly demarcated by several colors. Light-blue areas are characteristic of medium-stature forests of *R. harrisonii*, whereas white, purple, yellow and light-purple color features represent high-stature stands of *R. racemosa*. Light-green color is representive of low-stature forest.

6.3.4 *Mapping mangrove tree diameter and stand biomass*

We have shown the relevance of adjusting field-measured diameter and derived biomass (see Table 6.1) whenever there is a time gap between the acquisition of satellite images and the field sampling.

Table 6.1 Forest parameters of the studied mangrove area (Cameroon estuary).

Plot ID	Stand attributes				Adjusted parameters		
	Mean D_{130} (cm)	Mean height (m)	Density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Mean D_{130} (cm)	AGB (t DM ha^{-1})	Carbon stock (t ha^{-1})
LSF1	5.26	4.73	9425	23.78	4.29	115	54
LSF2	6.04	4.90	7650	26.52	5.02	142	67
LSF3	6.05	5.13	6575	21.76	5.05	112	53
LSF4	6.06	5.03	7925	26.99	5.06	147	69
LSF5	6.64	5.73	5750	23.07	5.62	122	57
LSF6	7.37	6.40	4850	23.68	6.34	133	63
LSF7	7.98	7.24	4450	25.70	6.94	147	69
MSF1	9.03	10.16	3150	23.21	7.97	139	65
MSF2	9.18	11.69	3000	22.53	8.13	133	63
MSF3	9.44	9.60	3000	23.40	8.37	148	70
MSF4	10.82	11.88	1875	19.92	9.74	137	64
MSF5	11.60	10.62	4200	46.88	10.41	328	154
MSF6	12.04	12.40	1300	16.20	10.95	151	71
MSF7	12.66	14.27	1775	24.64	11.57	185	87
HSF1	20.25	16.32	775	31.09	19.11	320	150
HSF2	20.41	17.60	725	30.01	19.27	310	146
HSF3	24.03	21.95	675	32.22	22.90	308	145
HSF4	25.30	20.58	775	41.43	24.16	432	203
HSF5	25.89	23.92	750	40.71	24.78	414	195
HSF6	26.67	25.11	450	34.36	25.56	428	201

LSF = Low-Stature Forest; MSF = Medium-Stature Forest; HSF = High-Stature Forest.

The procedure following this first step consists of testing whether the correlation between these adjusted structural parameters and the corresponding textural indices (based on the most prominent factorial axis *i.e.*, PCA1) is meaningful. It should be noted that the wood density (p) used here in the calculation of adjusted biomass was 0.779. As expected, our findings revealed a significant relationship between the PCA1 coordinates (textural indices) and the mean adjusted quadratic diameter ($Diameter = PCA1/0.022 - 0.180$ $R^2 = 0.84$; $P < 0.05$) and above-ground biomass (AGB) ($AGB = PCA1/0.0015 - 0.1202$; $R^2 = 0.92$; $P < 0.05$). The resulting map revealed that the mean quadratic diameter tends to be higher in areas characterized by important sediment supply (convex meander bends) and lesser in zones lacking fresh mud (concave banks and the inner mangrove forest) (Fig. 6.7 A).

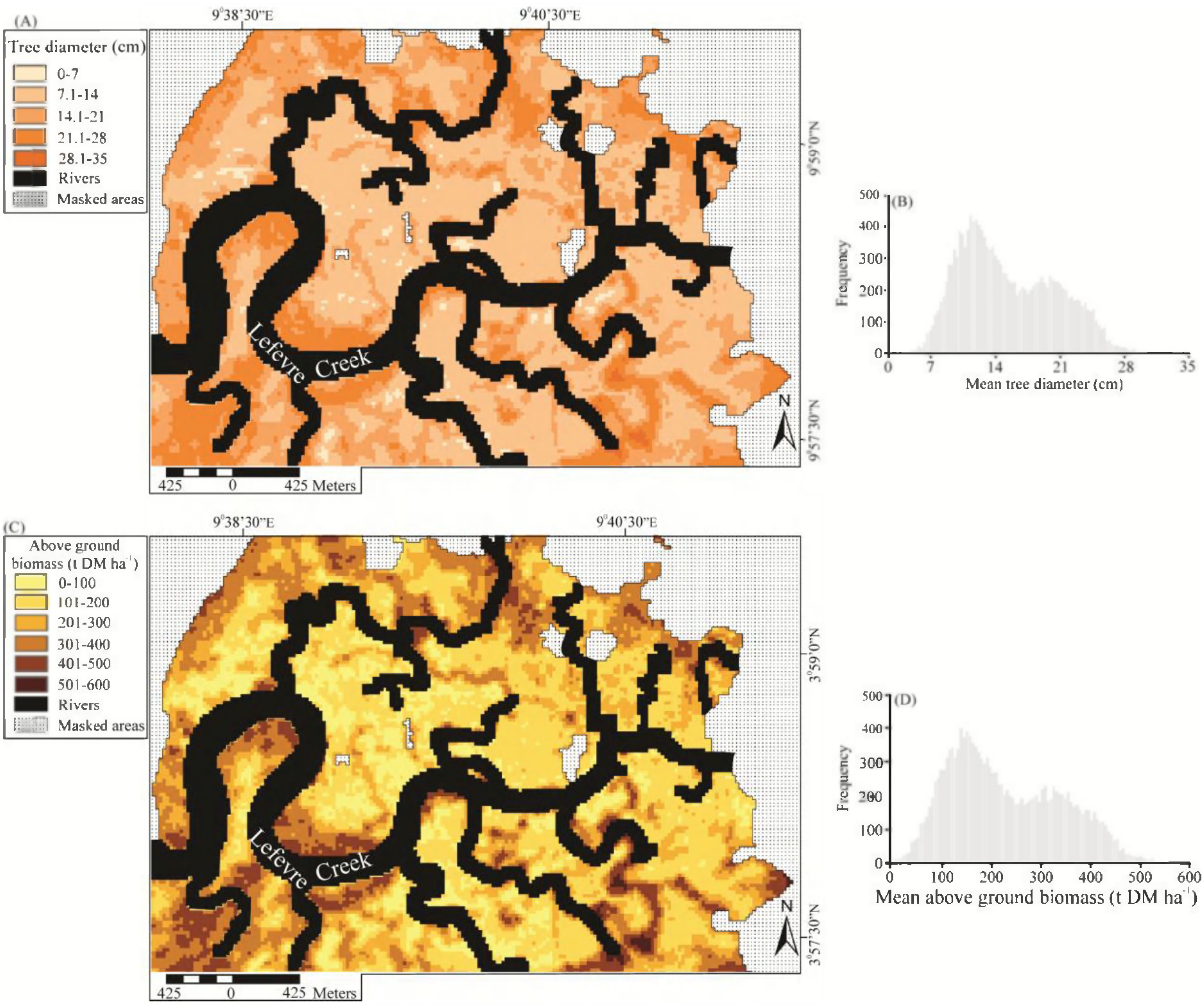

FIG. 6.7 Distribution of mean quadratic diameter and mean biomass in the Cameroon estuary. (A) FOTO-inverted map of mean quadratic tree diameter, (B) Frequency distribution of stem diameter, (C) FOTO-derived map of mangrove biomass (expressed in tones per dry matter per hectare (t DM ha^{-1}), (D) Frequency distribution of mangrove standing biomass. Notice the marked bimodal distributions in C and D that denotes the two dominant vegetation structures (medium and high stature forests).

In spite of this difference in mud deposition, the two-way ANOVA test had shown that the general soil properties in low, medium and high-stature forests were not statistically different (P > 0.05) (Table 6.2). On one hand, as illustrated in Fig. 6.7 B, trees with mean quadratic diameters < 8 cm were less represented. On the other hand, stems diameters ranging from 9 to 14 cm were largely frequent followed by those comprised between 20 and 22 cm. The other diameter classes (*i.e.*, 15 cm ≤ diameter ≤ 19 cm and 23 cm ≤ diameter ≤ 35 cm) were fairly recorded. In addition, we noticed a local directional gradient in the mean quadratic diameter sizes from the convex meander bends towards the inner forests.

With regard to the mean quadratic biomass distribution, the total AGB estimated reached impressive amounts of up to 600 t DM ha^{-1} (Fig. 6.7 C). We furthermore noticed that mean quadratic AGB ≤ 300 t DM ha^{-1} covered more than 80% of the biomass map (Fig. 6.7 C). Although AGB with fairly high values (*i.e.*, 200 t DM ha^{-1} < AGB < 300 t DM ha^{-1}) were sporadically mapped those ranging from 100 to 200 t DM ha^{-1} were widely distributed across the study area (Fig. 6.7 D). In contrast, small AGB (*i.e.*, < 100 t DM ha^{-1}) , though recorded in the concave banks, was mostly found in the inner mangrove forest located between 9°38'-9°39'E and 9°57'-9°60'N. The other classes, composed of large AGB (*i.e.*, > 300 t DM ha^{-1}), were most frequent in the convex meander bends.

Table 6.2 General soil characteristics of the study area.

Soil characteristics	Forest type								
	Low-Stature			Medium-Stature			High-Stature		
	NS	Mean	CV	NS	Mean	CV	NS	Mean	CV
Clay (%)	7	28.78	0.32	7	31.55	0.22	6	31.07	0.27
Fine silt (%)	7	15.83	0.40	7	16.34	0.28	6	18.00	0.32
Coarse Silt (%)	7	10.55	0.76	7	8.84	0.39	6	8.17	0.39
Sand (%)	7	8.67	0.39	7	9.25	0.55	6	8.99	0.58
OM (Calcimetry; %)	7	26.43	0.32	7	26.94	0.20	6	22.38	0.33
Organic C (%)	7	11.70	3.30	7	11.11	2.71	6	9.40	2.98
Total N (%)	7	0.42	0.10	7	0.48	0.09	6	0.42	0.12
C/N	7	29.15	0.29	7	22.95	0.13	6	20.66	0.27
Conductivity (mV)	7	25.87	0.37	7	20.16	0.94	6	19.81	0.64
pH water	7	6.19	0.03	7	6.19	0.05	6	5.81	0.27

OM = Organic Matter, NS = Number of Samples and CV = Coefficient of Variation.

Comparison between the FOTO inverted mean quadratic diameter and the average adjusted field diameter revealed a bias ($D_{130bias} = D_{130FOTO-inverted} - D_{130adjusted}$) of *ca.* - 0.007 cm (Fig. 6.8 A). Regarding the mangrove AGB, the estimated bias ($AGB_{bias} = AGB_{FOTO-inverted} - AGB_{adjusted}$) was relatively low (~1.06 t DM ha^{-1}) (Fig. 6.8 B). The rms errors of mean quadratic diameter and AGB mapped were 1.88 cm and 19.72 t DM ha^{-1}, respectively. In both cases, accordingly, the one to one scatter plot between the FOTO-inverted and adjusted structural (mean diameter) and functional (average AGB) parameters was obvious and accordingly less sparse around the line of slope 1 (see Fig. 6.8).

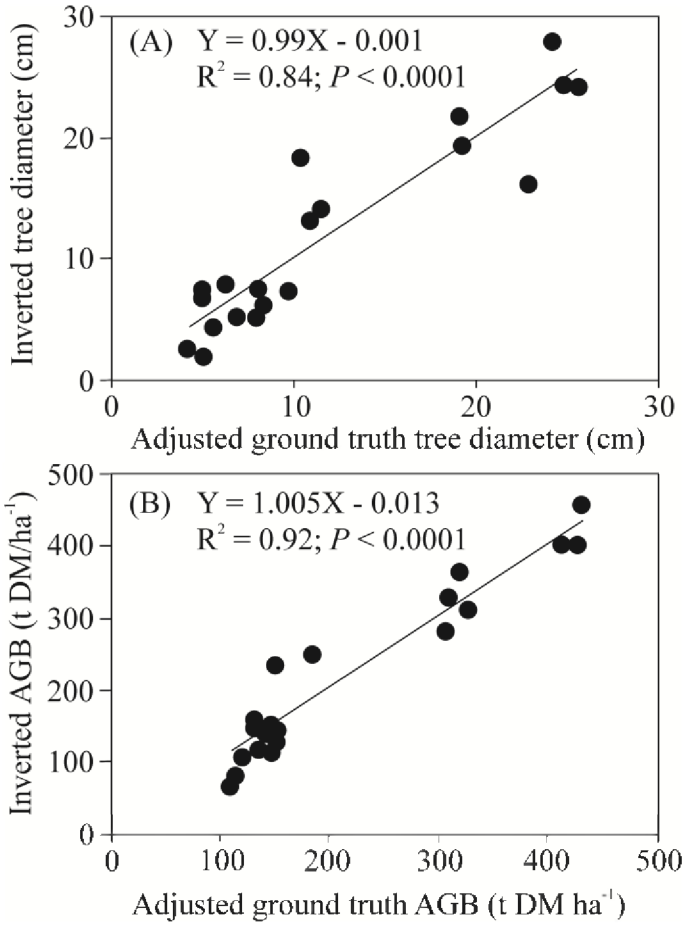

FIG. 6.8 Fitting between A) FOTO-inverted and adjusted ground truth structural parameter (mean quadratic diameter) and B) FOTO-inverted and adjusted ground truth functional feature (mean biomass).

6.3.5 *Mapping mangrove carbon stocks*

We have already underlined that there is a conservative ratio between the mean adjusted quadratic AGB and the ecosystem carbon storage. Based on this ratio, we estimated mangrove C stocks (see Table 6.1). On the other hand, we have also established a linear model between the AGB and the PCA1 values. We combined both aforesaid relationships to infer a simple model involving PCA1 and carbon stocks ($C = (PCA1/0.0015 - 0.1202) \times 0.47$). We afterwards computed this allometric equation to derive the map of carbon stocks across the mangroves in Cameroon estuary. We therefore noticed that the above ground C pools were sizeable (Fig. 6.9 A). In fact, our results indicated that C storage in mangroves of the Cameroon estuary exceeded 250 t ha^{-1}. The spatial distribution of carbon stocks (Fig. 6.7 B) like those of tree diameter and AGB (see Fig 6.7 B & D) shows two well-defined peaks. The first peak, at a C value of 100 t ha^{-1}, corresponds to the areas dominated by medium stature forests, while the second peak, at 200 t ha^{-1}, refers to stands covered by high stature forests.

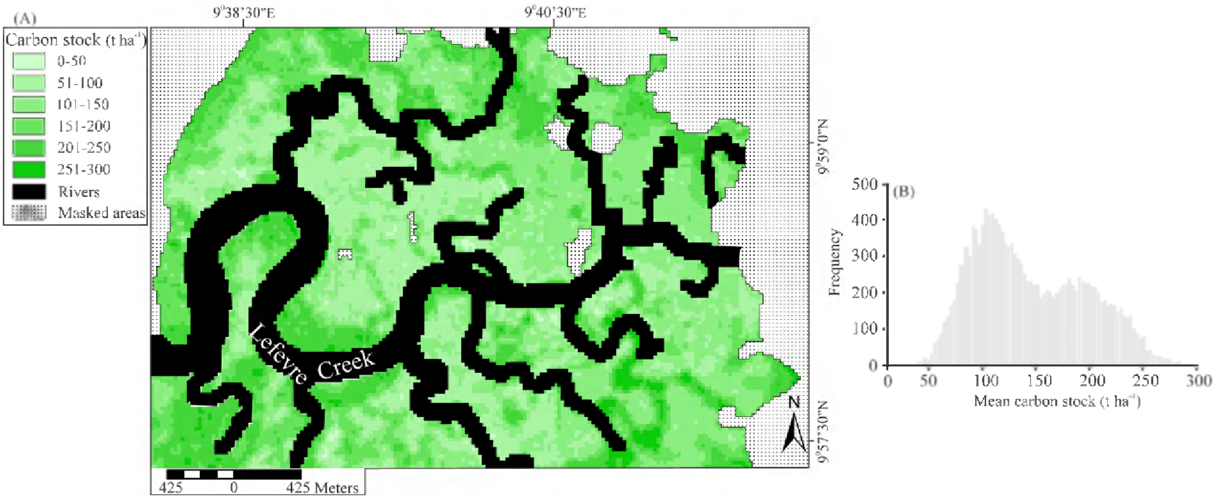

FIG. 6.9 (A) Map and (B) frequency distribution of above ground carbon stock in mangroves of the Cameroon estuary.

6.4 DISCUSSION

Establishment of several regional databases featuring field-measured forest parameters and corresponding canopy images is one of the main step that would lead to the development of a standardized method for canopy texture measurement (Proisy *et al*., 2007). Through the results presented in this study, we have contributed to achieve this expected goal. We applied the FOTO method to VHR QuickBird images of mangroves and the results yielded were meaningful like those previously recorded in Amazonian forests (Barbier *et al*., 2010). Other published studies involving the FOTO method have also reached similar strong findings (see Couteron *et al*., 2002; Couteron *et al*., 2005; Couteron *et al*., 2006; Barbier *et al*., 2006; Proisy *et al*., 2007; Barbier *et al*., 2011). The 2-D Fourier transforms of the satellite images, in a study region of *ca.* 2260 ha in Cameroon estuary, have shown that the mangrove exhibited two main vegetation structures corresponding to either medium or high-stature forests dominated by trees of *Rhizophora*.

The first dominant pattern (fine-grained texture) had a mean standardized spectrum dominated by spatial frequencies above 20 cycles hm^{-1} (Fig. 6.5 A). These trees subsisted on firm fibrous and uneven substrates resulting from erosion (concave shorefronts) or non-deposition (inner forest) phenomenon. Under such conditions, it may be advantageous for the trees to invest more fixed carbon in growing numerous root systems to maximize water gain (Anthony 2004; Alongi 2009). This type of complexity in root architecture was observed in our sampling areas. Furthermore, trees growing in the medium-stature stands were not harvested and accordingly formed a closed and zoned homogeneous canopy that could be easily discriminated in the FOTO map of mangrove canopy. The second pattern, though less frequent than that aforesaid, showed a peak value in intermediate spatial frequencies (~7 cycles hm^{-1}). Windows displaying such coarse textures were often recorded in floodplains with marked substrate accretion rates (convex shorefronts). Hence, the trends in landscape features seemed to be partially due to the difference in stand growth stage. The latter being influenced by both hydrodynamic processes and prop root complexity since the tidal flow within mangrove areas, as well as the distribution and deposition of soil particles and mineral nutrients, depends to a large degree upon the submerged root density (Madza *et al.*, 2005).

At first sight, the variation in landscape features could denote differences in the sediment composition. However, the results of this study showed that soil characteristics were similar across the sampling sites, although different types of vegetation structure were currently observed. On the one hand, the inner mangrove forest, mainly characterized by the firm fibrous sediments, may have received high inputs of organic matter directly as wood litter (past wood harvesting) (Baltzer *et al.*, 1995; Tonye & Akono 1998). On the other hand, large quantities of muddy substrates (rich in organic carbon and detritus) are daily deposited by tides or rivers in the newly created mangrove surface located in the fringed convex bends. The greater activities of microbial degraders when substrate is permanently wet enhance litter degradation in this latter mangrove environments (Kristensen *et al.*, 2008) thus creating a suitable conditions for tree growth. Another obvious factor that could have shaped the vegetation patterns in the mangrove forest under study is the level of human-induced disturbances. In fact, it has been clearly pointed out that the use of chain saws in the logging operations constituted the main cause that disrupts mangrove cover in the Cameroon estuary (Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009). But according to our results, windows with extreme coarseness properties (due to large circular and elliptical man-induced gaps) were fairly discriminated denoting that excessive wood extraction was un-common in our study area compared to the peri-urban settings where it is greatly accented (see Chapter 3, 4 and 5). Therefore, one could summarize that the patterning of mangrove vegetation structure might be related to the age of the stands, linked to mud bank dynamic processes (Cunha-Lignon *et al.*, 2009a, b).

Previous studies devoted to map the structural and functional parameters of mangrove forests have been focused solely on leaf area index, tree height and biomass estimation (Kovacs *et al.*, 2005; Simard *et al.*, 2006; Proisy *et al.*, 2007; Mitchell *et al.*, 2007; Simard *et al.*, 2008; Kovacs *et al.*, 2010). For the first attempt, we have produced a baseline map to quantitatively estimate the mean quadratic diameter distribution of tree and carbon stocks over the large and poor accessibility areas such as mangroves. The AGB of mangroves trees in the Cameroon estuary were almost similar to the values in French Guiana mangroves as documented by Proisy *et al.* (2007). However, our observed AGB were sometimes higher than those recorded in Australia (Briggs 1977), South Africa (Steinke *et al.*, 1995), Thailand (Tamai *et al.*, 1986; Komiyama *et al.*, 2000), Colombia (Simard *et al.*, 2008), Micronesia (Kauffman *et al.*, 2011) and Sundarbans (Mitra *et al.*, 2011). Likewise, we found that the above ground C pools were more important in some stands compared to the two latter sites (Donato *et al.*, 2011; Kauffman *et al.*, 2011; Mitra *et al.*, 2011). In fact, the Cameroon estuary provides ideal growing conditions for mangroves due to fresh water input (from the Mungo, Dibamba and Wouri Rivers) and considerable rainfall (~4000 mm average annual precipitation) that often led to high rate of seawater dilution. This coastal ecosystem is subjected to active mud sinks quite rich in organic matter and carbon reserve (see Table 6.2). For instance, the total transport of dissolved and particulate organic carbon of the Sanaga and Douala Bay Rivers reaches 0.79 t C year^{-1} (Giresse & Maley 1998). All aforesaid environmental factors are favourable to the AGB production and carbon sequestration. Of course, the maps produced in this study may prove useful for the monitoring and management of mangrove forests. In addition to this important outcome, we believe that the FOTO-inverted maps of average quadratic biomass and carbon stocks built here greatly illustrate the contribution of mangroves in the reduction of atmospheric CO_2 concentrations, especially in the current context of the global surface warming.

In this work, we used a structural and functional parameter inversion from image texture (VHR QuickBird data) to infer the spatial distribution of mangrove diameter, biomass and carbon stocks in a large extent. This approach is an alternative to the spatially extensive field surveys that are known to be laborious and very time-consuming (Cintrón & Schaeffer-Novelli 1984). The method is merely based on the relevance of the relationships that can be established between the FOTO indices and sampled tree parameters. Therefore, the first fundamental point that determines the accuracy of the approach presented here could be the influence of acquisition parameters on the FOTO index. The instrumentally-induced variations of the texture index were not found in our satellite data as the images were acquired under a single instrumental configuration. Accordingly, we did not apply the partitioned standardization which mitigates the variability resulting from varying acquisition parameters (see Barbier *et al.*, 2010, 2011). In such case, radiometric and geometric corrections are not often recommended since they contribute to increase the noise level (Ryan *et al.*, 2003) and accordingly could bias Fourier r-spectra (Proisy *et al.*, 2007). The second condition that renders this methodological procedure unbiased is to ensure a best overlay of the geo-registered field sampling plots with the satellite images. Thanks to the VHR QuickBird images and Garmin GPS instrument (maximum location error ~2 m) that have allowed us to respect the above mentioned requirement. Likewise, the good field knowledge was also very useful in recording the exact position of plots on the satellite image.

Thus, the resulting map of mean quadratic diameter, as well as that of the biomass, was accurate and unbiased since the linear fit between the FOTO inverted and the adjusted ground truth parameters matched the "one over one" line (see Fig. 6.9 A, B). Moreover, dispersion of points across the diameter and biomass ranges was quite close to the regression lines, thus reflecting relative low bias and rms errors. It is interesting to underline that zones displaying high or medium stature stands, respectively correspond to mangroves areas characterized by large or fairly important accumulation of biomass and carbon. As previously reported by Proisy *et al.* (2007), our results also show no trend towards saturation even for very high biomass values above 500 t DM ha^{-1}. This denotes the efficiency of the current methodological approach that, along with previous published works, used parameter inversion from image texture for mangrove structure and biomass mapping.

6.5 CONCLUSION

In the present study, we showed the potential of using the parameter inversion from image texture (obtained based on the FOTO method) to accurately map the spatial distribution of mangrove tree diameter and carbon stocks. Along with previous findings, this method was also found appropriate to estimate mangrove biomass over 2260 ha of unexplored forests. The 2-D Fourier transforms of the VHR QuickBird images (~1 m resolution) provided appreciable results. Indeed, our analysis revealed relative small bias either for diameter (~ -0.007 cm) or biomass (~1.06 t DM ha^{-1}). Likewise, we also recorded low values of rms errors for both diameter (1.88 cm) and biomass (19.72 t DM ha^{-1}). As carbon sequestration is a function of biomass production, we are confident that the map of carbon stocks is also less biased. Moreover, we found that the mangrove under study is dominated by trees with diameters ranging from 9-14 cm. Also, biomass comprised between 100 and 200 t DM ha^{-1} were recorded most frequent. Above ground C storage showed peak values at ~100 t ha^{-1} and ~200 t ha^{-1}. This is the first time that this type of results are produced for the Cameroon estuary and it would be very useful for monitoring this mangrove forests which is currently facing several combined threats such as over-harvesting, sand extraction, anarchic urbanization, climate change and sea level rise. In a wide context, the supplied data would be useful in the standardization of the relationships between textural indices and mangrove forest parameters.

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PLANCHE 7. Une stature monospécifique mature et non anthropisée d'*Avicennia germinans* (L.) Stearn (mangrove noire) dans l'estuaire du Cameroun. Dans ce site, la hauteur maximale d'*A. germinans* est de 41 m.

PLATE 7. A mature pristine monospecific stand of the black mangrove *Avicennia germinans* in the Cameroon estuary. In this stand, the maximum height of *A. germinans* is 41 m.

CHAPTER 7

MANGROVE SPATIAL STRUCTURE IN A MONOSPECIFIC STANDS OF THE BLACK MANGROVE *A. GERMINANS* (L.) STEARN IN THE CAMEROON ESTUARY

ADOLPHE NFOTABONG ATHEULL[1,2], NDONGO DIN[2] AND FARID DAHDOUH-GUEBAS[1,3]

[1]Laboratory of Systems Ecology and Resource Management, c/o Département de Biologie des Organismes, Faculté des Sciences, Université Libre de Bruxelles – ULB, CP 169, Avenue F.D. Roosevelt 50, B-1050 Bruxelles, Belgium.
[2]The University of Douala, Faculty of Science, Department of Botany, P.O. Box 8948 Douala, Cameroon.
[3]Laboratory of Plant Biology and Nature Management, Mangrove Management Group, Vrije Universiteit Brussel - VUB, Pleinlaan 2, B-1050 Brussels, Belgium.

Article to be submitted

ABSTRACT

One of the major components of forest stand structure is the spatial arrangement of tree positions and the distribution pattern of species. *Avicennia* (Acanthaceae) is considered an important colonizer of new estuarine areas. This genus comprises about eight species of which only one, namely the black mangrove *Avicennia germinans*, occurs in Cameroon mangrove forests. Through extension its complex of pneumatophores this species causes solidification of the soft substrate, hence facilitating the stabilization of coastal zones. In spite of this ecological importance, little is known about the patterning of *A. germinans* forest stands. In this contribution, we characterized the stand structure of this species in the Cameroon estuary. We located two sites in the landward margin and one on the seaward edge. There, we established 20 plots of 40 m × 40 m along belt transects, and subdivided each plot into 16 subplots of 10 m × 10 m. We measured the diameter, height and spatial coordinates of all *A. germinans* stems and finally determined the type of spatial arrangement of trees based on the on Ripley's *K*-function. Regarding the structural parameters, our results showed that the mean tree diameter, basal area and height were considerably higher on the seaward edge than in the landward margin. In the Cameroon estuary, trees of *A. germinans* were randomly distributed on almost one-half of the sampling plots and clumped at some scales on the remaining plots. Why our study did not exactly examine the key factor structuring the population of *A. germinans*, we assume that the zonation pattern of this species is driven by the great dispersal events and high rate of seedling mortality. In addition to our findings, it is important to develop a more complete characterization of the stand structure of *A. germinans*. We believe this objective can be achieved by analyzing endogenic organisation processes (phenology, seed production, wood structure, growth etc...) that occur within the growing environment of this species.

Keywords: Vegetation structure, Spatial pattern, *Avicennia germinans*, Mangrove, Cameroon estuary

7.1 INTRODUCTION

Quantitative assessment of the distribution of trees in a forest stand is an initial step towards understanding the forest community dynamics (Shimatani & Kubota 2004). It is also important in the execution and maintenance of re-afforestation programs, because tree arrangement influences tree development (Bosire *et al.*, 2003, 2006), faunistic recruitment (Bosire *et al.*, 2004), environmental processes (Bosire *et al.*, 2005a) and overall functionality and management of the mangrove (Bosire *et al.*, 2008). In turn, spatial arrangement of mangrove species across the intertidal zone is influenced by several factors, including tidal flooding (Cohen *et al.*, 2004), salinity variations (Cardona-Olarte *et al.*, 2006; Krauss *et al.*, 2008), nutrient availability (Feller *et al.*, 2007; Whigham *et al.*, 2009), differential propagule dispersal (Rabinowitz 1978), establishment (Di Nitto *et al.*, 2008), predation (Smith 1987; Dahdouh-Guebas *et al.*, 2002; Bosire *et al.*, 2005b), movable substrate (Casteneda-Moya *et al.*, 2006) and the presence of anoxic sediments (Lara & Dittmar 1999).

In the intertidal zone, species-specific tolerance to variation in the physical environment depends on their capacities to withstand or adapt to the regular variations of the abiotic conditions where they grow (Tomlinson 1986; Twilley *et al.*, 1996; Koch & Snedaker 1997; Saenger 1998; Din *et al.*, 2002a; Jayatissa *et al.*, 2002). The distribution of the species according to the gradients of abiotic factors' means that mangroves as well as their associated fauna exhibit strong zonation (e.g. Matthijs *et al.*, 1999; Dahdouh-Guebas *et al.*, 2002). Dynamically, the mangrove can be considered as pioneering vegetation, with representatives of the genus *Avicennia* being the best colonizers (Osborne & Berjak 1997; Fromard *et al.*, 2004). The ability of *Avicennia* propagules to remain buoyant for long periods of immersion in salt water would allow dispersal over potentially great distances (Rabinowitz 1978; Dodd *et al.*, 2000), although this is not necessarily the case for mangrove species more typical of mature stands (Di Nitto 2010). In mature stands, *Avicennia* is gradually replaced in the long term by other species with slower growth which profit from the transformation of the edaphic conditions by the pioneer mangrove species.

Avicennia germinans Stearn (Acanthaceae) is a regular component of the intertidal mangrove communities (Dodd *et al.*, 2000). In the Cameroon estuary, this "black mangrove" is a major ecological indicator. Its presence causes the solidification of the substrate, leading to the transformation of the initial abiotic conditions which facilitate the development of other species. For this reason, the zone where *A. germinans* occurred has been described by Din *et al.* (2002a) to be the diversification centre of taxa in the Wouri (Cameroon) estuarine mangrove. Thus, knowledge of the stand structure could help to better understand the population dynamics of *A. germinans* and have clear guidelines for sustainable management. However, there is limited information describing the spatial structure of the mangrove species

A. germinans. Studies conducted so far on this species have, however, typically focused on evaluating its evolutionary divergence (Dodd *et al*., 2000), growth conditions (Patterson *et al*., 1993; Din *et al*., 2002a; Whigham *et al*., 2009; Alleman & Hester 2011; Pickens & Hester 2011), changes in cover (Perry & Mendelssohn 2009; Everitt *et al*., 2007, 2008, 2010), genetic diversity (Ceron-Souza *et al*., 2005; Salas-Leiva *et al*., 2009) and hydrolic architecture (Robert *et al*., 2011).

The goals of the present research were (a) to characterize the stand structure of *A. germinans* in the Cameroon estuary and (b) to analyse its spatial distribution with respect to site location.

7.2 MATERIAL AND METHODS

7.2.1 *Site description*

The research covers three sites within the Cameroon estuary (Fig. 7.1). The sites are crossed by a network of small channels which received fresh water from the Wouri and Dibamba Rivers.

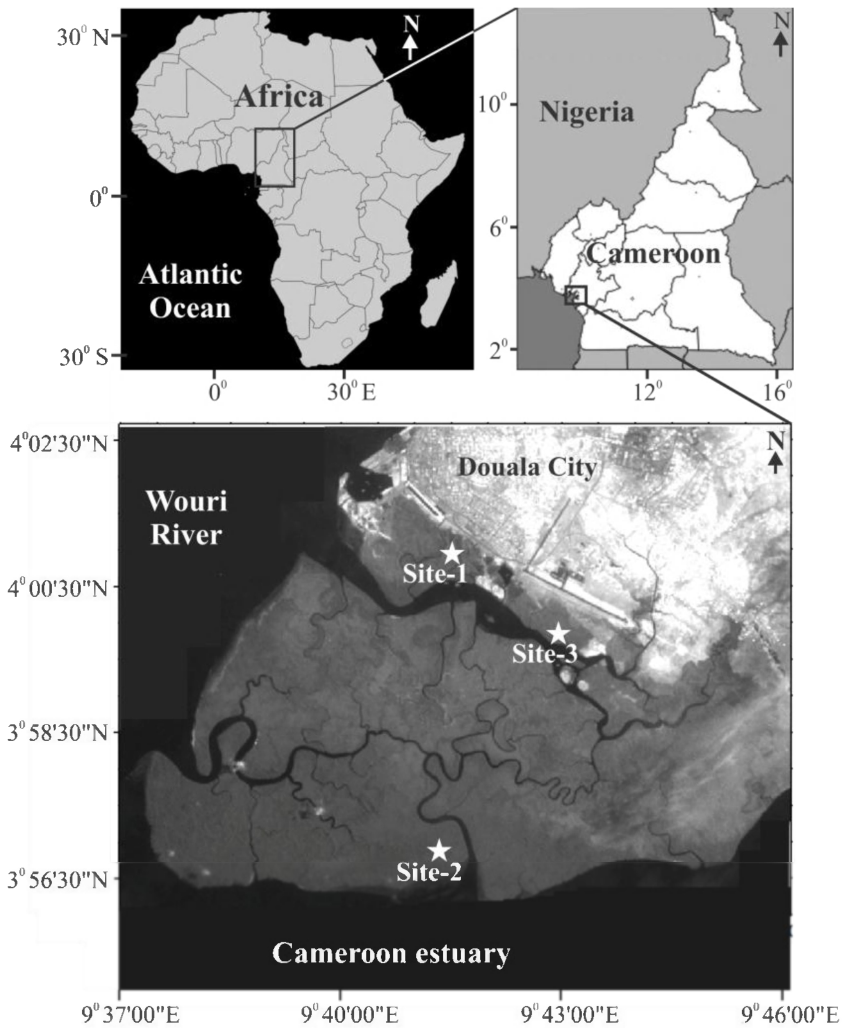

FIG.7.1 Satellite image (taken in July 1987) of the study area showing the location of each sampling sites in Cameroon estuary.

Sites 1 and 3 are further from the sea than site 2 is. All sites are dominated by *A. germinans*. The amplitude of the semidiurnal tides ranges between 0.14 and 1.87 m. The mangrove forests have been designated as 'protected areas' and the studied sites are relatively undisturbed. The area has wet season extending from March-November. The rate of seawater dilution is very high during this period and lesser in the dry season (December-February). Mangrove phenology and physiognomy varies between sites. Spatial distribution of *A. germinans* depends not only on the modes of seed production but also on seed dispersion (Din *et al*., 2002a). Seed production was more prolific in site 2 than it was in sites 1 and 3. In both latter sites, however, seeds were commonly trapped by a carpet of pneumatophores and became stranded, while in site 2, they are greater dispersed by tidal action. Mature trees were dominant in site 2 whereas few senescent and numerous young trees were usually found in sites 1 and 3.

7.2.2 *Characteristics of species studied*

Avicennia is a small genus, comprising about eight species (Tomlinson 1986). Of the eight species, *A. germinans* is the only species encountered within the Cameroon mangrove forest. It usually dominates higher elevation sites. Where this species settled, it may have formed mixed stand with *Rhizophora* spp. *A. germinans* has an epigeal germination with cotyledons that expand and are exposed (Proisy *et al*., 2009). Tree height and diameter of *A. germinans* can reach 40 m and 320 cm, respectively, in the Cameroon estuary. Although seed production is high, edaphic factors are unfavourable for their growth during their early stage (Din *et al*., 2002a).

7.2.3 *Field measurement*

A transect of 40 m width was established perpendicular to the main water channel across each sites. Data collection was carried out within 1600 m^2 (40 m×40 m) quadrats laid out along each of the three transects. Quadrats were not adjacent since they were located between neighbouring channels or in less muddy substrate. A total of 5, 7 and 8 plots were sampled in sites 1, 2 and 3, respectively. Using stakes and cords, each plot of 40 m×40 m was delimited and subdivided in 16 subplots of 10 m×10 m called "small squares".

In each "small square", the spatial coordinates (*x*-*y*) of all stems were recorded. To avoid sampling the same tree twice, a red paint mark was applied to each stems sampled. The position occupied by each *Avicennia* tree with a $D_{130} \geq 5$ cm was mapped at a scale of 1/500 in each subplot. Each individual was thus identifiable both by a number and by its coordinates. Additionally, the vertical profile of the tree crown was projected to ground level and delineated using a string and wooden stakes (see Din *et al*., 2002a). Each polygon obtained was converted to a circle of the same area in order to facilitate computation of the site surface-area cover by the crown of adult trees.

Structural parameters such as tree height and diameter (D_{130}) were measured using a clinometer and a slide caliper, respectively. Diameters between 5 and 25 cm were directly measured. For trees larger than 25 cm in diameter, girths (G in cm) were taken and later converted to diameter using the formula $D_{130} = G_{130}/\pi$. For trees with a 1.3 m height (measured along the stem) from the base of the tree on mangrove soil, the D_{130} recorded was the average of all stem diameters (Dahdouh-Guebas & Koedam 2006b). Trees with a $D_{130} < 5$ cm were not considered in the present study as our interest was to focus on readily exploitable stems preferred by local fisherfolk.

7.2.4 *Statistical analysis*

The spatial point pattern statistic involving the Ripley's *K*-function (Ripley 1977; Diggle 1983), *K* (*r*) was used to assess the distribution of *A. germinans* in the three sites. This univariate analysis (e.i., intraspecific association) was performed using a ADE-4 package (Thioulouse *et al.*, 1997). To achieve this, a 1 m step up to $r = 12$ m was considered during the computation of the *K* function. The local weighting method proposed by Ripley (1977) was used to correct the edge effect. The *K* (*r*) measure the average number of trees located within a given radius *r* of each sampled trees and test the null hypothesis of complete spatial randomness. This was made by means of the Monte Carlo simulations (with 1000 iterations). From these simulations, a 95% confidence envelop were calculated and used to test the significance of the null hypothesis. In practice, the following linearized *L*-estimator is used during the computation of the Ripley's *K* function (Besag (1977).

$$L(r) = \sqrt{K(r)/\pi} - r$$

when $L(r) = 0$ the pattern is completely random; the distribution becomes regular if $L(r) < 0$ and clumped if $L(r) > 0$. For easy interpretation of the *K* (*r*), the above function is commonly represented in a graphic form. As such, the spatial pattern is considered clumped or regular when the Ripley's *K*-function is above or below the confidence envelop, respectively. For complete spatial randomness, this function remains inside the confidence envelops.

In order to assess the mangrove vegetation structure in each site, the number of individuals was plotted against the distribution of tree diameters. Likewise, the variation of the diameters within each plot was also analyzed. These analyses were implemented in a Statistical Package for Social Sciences (SPSS) software, *version* 16.0.

In each site, the average density and height of the individuals was calculated. Basal area was computed from the mean diameters by site by applying the standard formulas (Cintrón & Schaeffer-Novelli 1984). One way-ANOVA was used to compare the aforesaid structural parameters between sites. The percentage of coverage for each site was calculated by estimating the ratio between the area covered by the crown of adult trees on site and the total surface area of the site.

7.3 RESULTS

7.3.1 *Structural characteristics of sampling sites*

In a total surface area of 32,000 m^2, we recorded 90 trees in site 1, 65 in site 2 and 104 in site 3. The corresponding mean tree density was similar between site 1, 2 and 3 ($F = 2.78$; d.f. = 2; $p > 0.05$) (Table 7.1). However, the mean basal area ($F = 19.07$; d.f. = 2; $p < 0.001$) as well as the average tree diameter ($F = 24.15$; d.f. = 2; $p < 0.001$) was significantly different in site 2 compared to site 1 and 3 (Fig. 7.2).

Table 7.1 Structural parameters of the three sites sampled.

Sampling sites	Structural parameters			
	Mean density (trees ha^{-1})	Mean basal area (m^2 ha^{-1})	Mean D_{130} (cm)	Mean height (m)
Site 1	112.50 ± 60.43	23.26 ± 8.19	21.06 ± 3.58	12.45 ± 7.35
Site 2	58.04 ± 13.84	42.01 ± 11.80	42.01 ± 14.61	24.43 ± 15.25
Site 3	81.25 ± 38.96	26.16 ± 9.16	27.00 ± 6.03	15.14 ± 9.98

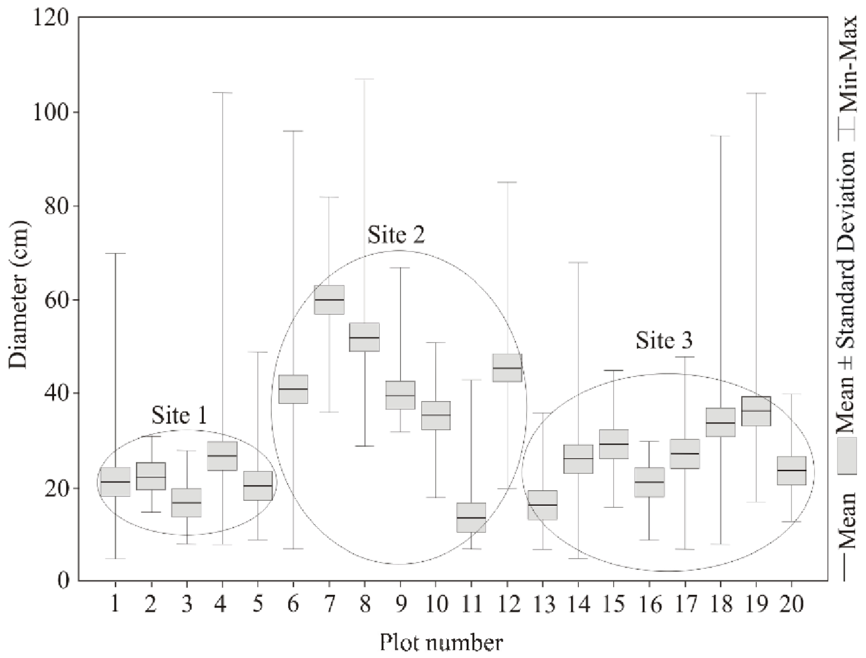

FIG. 7.2 Distribution of diameters in different sampling sites.

The distribution of the diameters within each plot shows two distinct assemblages (Fig. 7.3). The frequency distribution of the *A. germinans* tree diameters in the mangroves of the Cameroon estuary decreases greatly between the first and seventh classes in sites 1 and 3 (Fig. 7.3). In more heterogeneous stands like site 2, adult plants (35 cm ≤ D_{130} ≤ 55 cm) were most abundant.

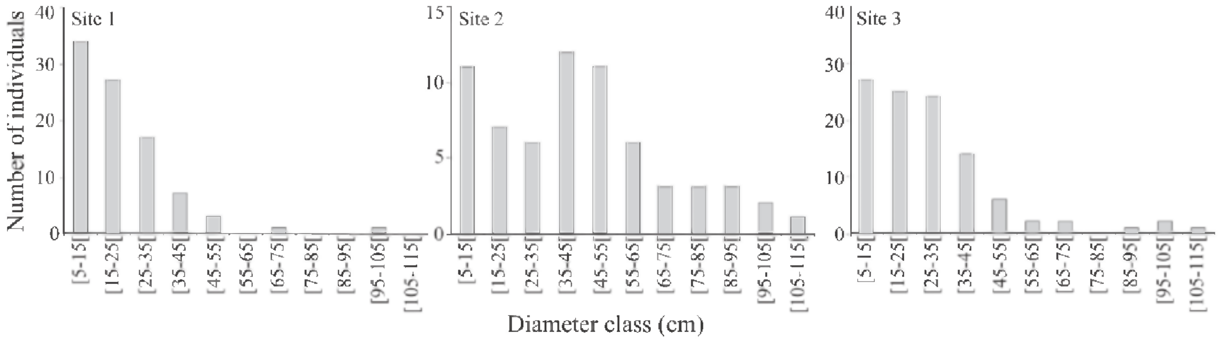

FIG. 7.3 Distribution of number of *A. germinans* trees according to diameter class.

The number of small squares without any individuals was 33, 74 and 78 in sites 1, 2 and 3, respectively. Therefore, the total surface area covered by the crown of *A. germinans* was 4,700 m^2 in site 1; 3,800 m^2 in site 2 and 5,000 m^2 in site 3 (Table 7.2).

Table 7.2 Percentage of coverage of each site by calculation of the ratio between the site surface area covered by the crown of *A. germinans* trees (SACC) and the total site surface area (SA). NI represented the number of individuals, respectively.

Plots	NI	SA	SACC (m^2)	SACC/SA (%)
Site 1	90	8000	4700	58.75
Site 2	65	11200	3800	33.92
Site 3	104	12800	5000	39.06

The 259 *A. germinans* plants were in fact, distributed in an area of 13,500 m^2. Taking into account the total surface area of each site, site 1 had a higher coverage (58.75%) by the crown of *A. germinans* trees than sites 3 (39.06%) and 2 (33.92%) (Table 2).

7.3.2 *Spatial pattern of A. germinans trees*

A map illustrating the spatial distribution of *A. germinans* in each plot of the three sample sites is showed in Fig. 7.4. *A. germinans* was not regularly distributed in the three sample sites (Fig. 7.5). In site 1, the spatial arrangement of this species was apparently random excepted plot 4 which revealed a clumped distribution at scale up to *ca.* 3 m. Similarly, trees of *A. germinans* were randomly distributed in site 2 with exception of clumped pattern at scales 2-3.5 m, 2-5 m, 4-10 m, > 3 m, 6-11 m in plots 6, 8, 9, 11 and 12, respectively. In site 3, a completely spatial clumped arrangement of trees was found in plot 16. Apart this plot, site 3 generally showed a random configuration of trees with exception of clumped distribution at scales > 2.7 m, 5-9 m, > 5 m and 5.8 m in plots 15, 17, 18 and 20, respectively (Fig. 7.5).

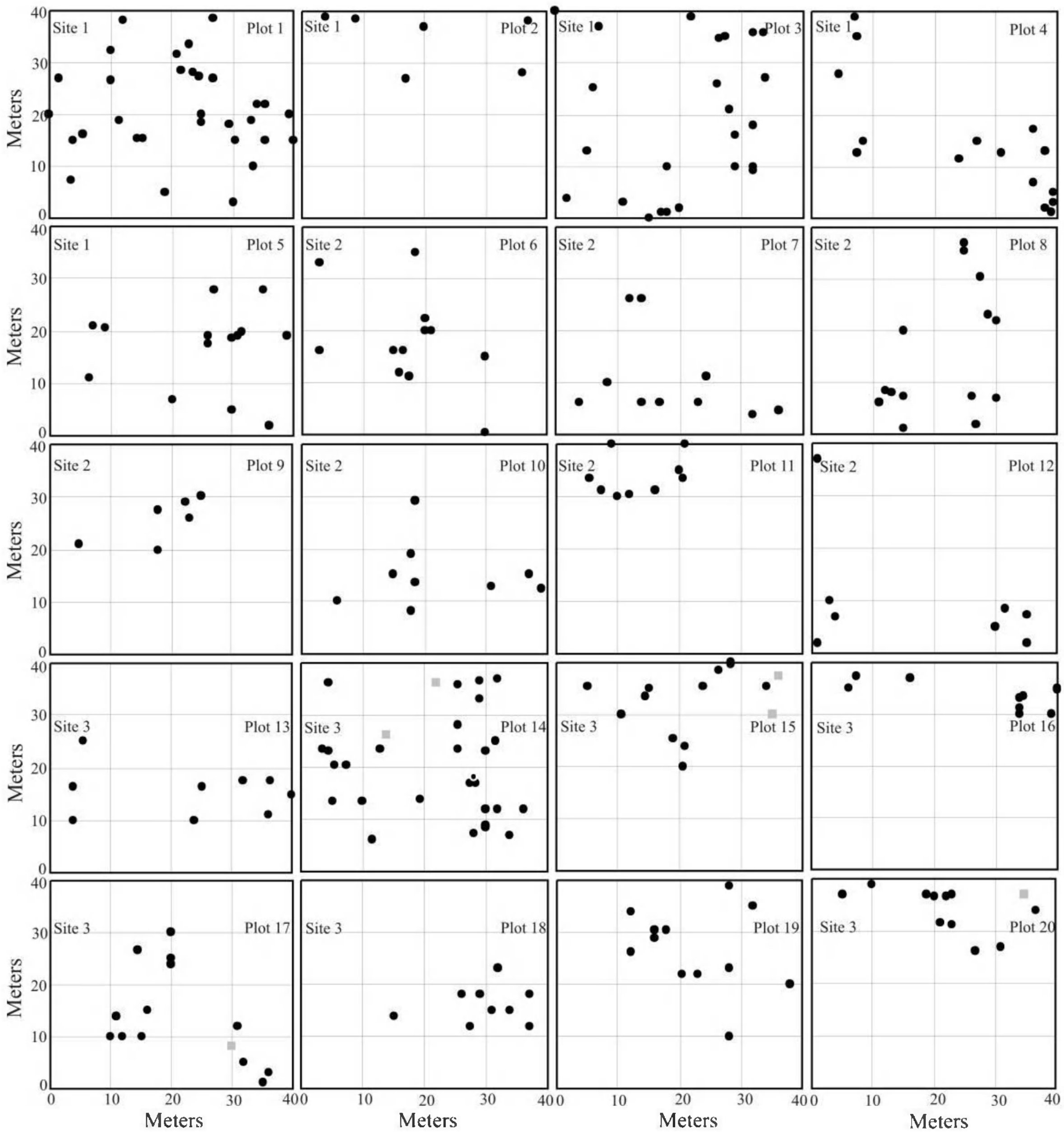

FIG. 7.4 Map showing spatial distribution of *Avicennia germinans* trees in each of the three sampling sites. Each dot represents the position of an *A. germinans* trees within a plot of 40 m×40 m. Note that the grey square represents the position of *Rhizophora* in some mixed stands.

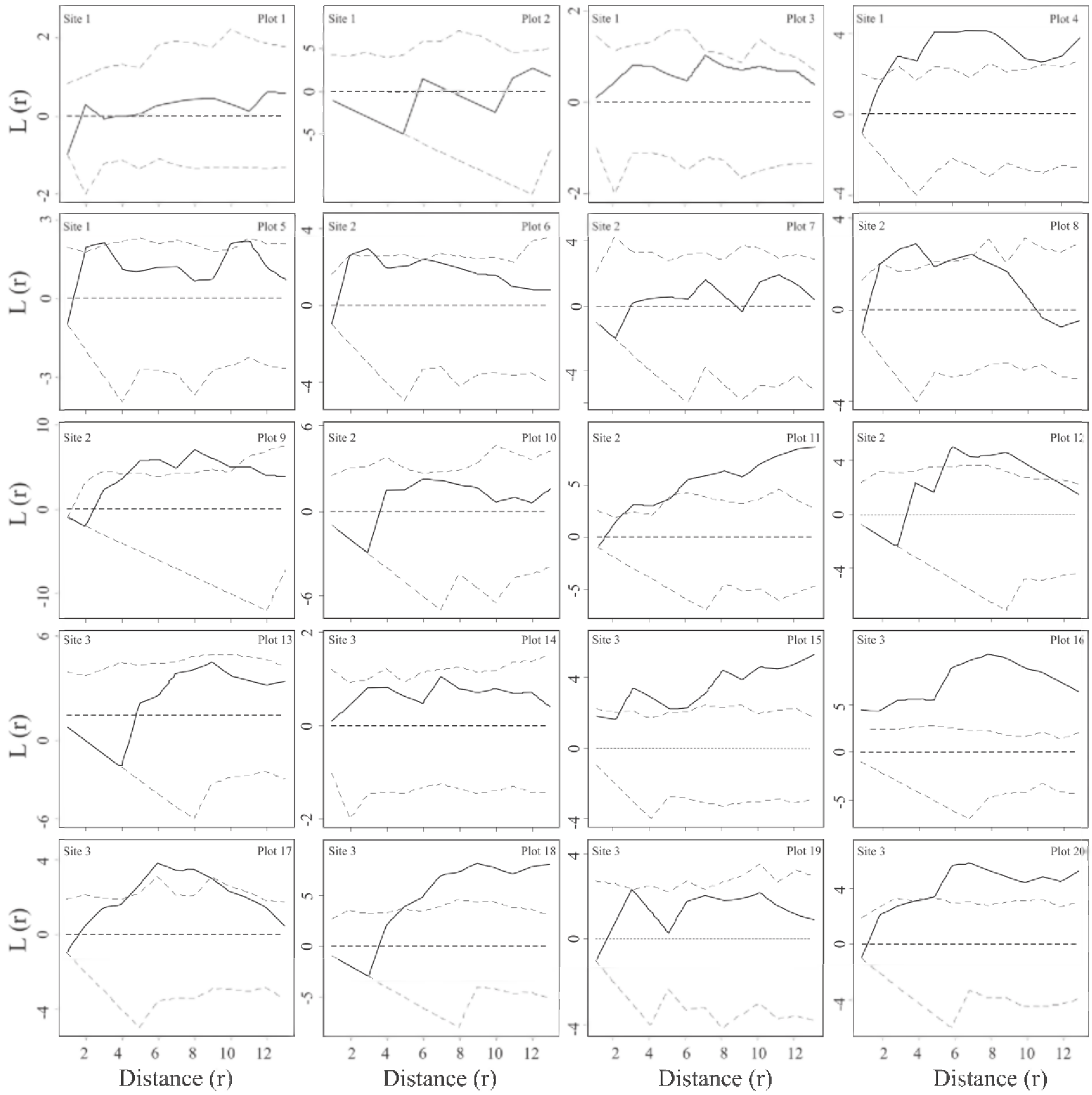

FIG. 7.5 Second-order spatial analysis of distribution patterns (solid line) of *A. germinans* in three monospecific sites using linearized *L*-function, *L(r)*, in Cameroon estuary. The two dotted lighter grey lines represent the corresponding 95% confidence intervals of random distribution.

7.4 DISCUSSION

One of the major components of forest stand structure is the spatial arrangement of tree positions and the distribution pattern of species (Ludwig & Reynolds 1988; Legendre & Legendre 1998; Kint *et al*., 2004; Souza & Martins 2005; Luo *et al*., 2010). Adult *A. germinans* in the mangroves of Cameroun had relatively large diameters consistent with their low density, generally accentuated by the important surface area occupied by their pneumatophores. Generally, few large *A. germinans* trees fit in a 400 m^2 plot (Din *et al*., 2002b). The way large trees are located in a plot with respect to their neighbour affects stocking and the subsequent growth of individuals and yield of the stands (Jayaraman 2000;

Bosire *et al*., 2008). Our results indicated that the tree density was similar between the three sites whereas the basal area and diameter were significantly higher in site 2 compared to the others. Indeed, stem densities in general negatively correlated with diameter and basal area (Satyanarayana *et al*., 2002).The basal area as well as diameter is a good parameter to express the level of development of a stand (Cintrón & Schaeffer-Novelli 1984). In this study case, their relatively low value confirms the young character of the formations in sites 1 and 3. In these sampling sites, some mangrove areas exhibited the characteristics of an immature stand (rejuvenating zone) with few sparse senescent trees. Differences in the diameter and basal area did not always depict clearly the occupation of a site. For instance, the large trees in site 2 were better represented by the crown sizes than stems numbers. By contrast, Dahdouh-Guebas *et al*. (2004a) found that in Gazi Bay, Kenya, in a mangrove stand co-dominated by *Rhizophora mucronata* Lamk. and *Avicennia marina* (Forssk.), Vierh. tree stems better represented the importance values of the species.

The areas surrounding the stems were commonly occupied by a continuous cover of *Avicennia* pneumatophores, a genus whose root complex is known to adapt to micro-topographical irregularities (Dahdouh-Guebas *et al*., 2004b; Dahdouh-Guebas *et al*., 2007). *A. germinans* propagules may, in turn, have higher probability of becoming trapped by a combination between topographic depressions and pneumatophore density. However, as observed in our study area (sites 1 & 3), senescent trees are often unable to produce large number of propagules.

Our analysis of the spatial pattern of *A. germinans* indicated that trees of this species were randomly distributed on almost one-half of the sampling plots and clumped at some scales on the remaining plots. *A. marina* has similar spatial distribution in the Shenzhen Bay, South China (Luo *et al*. 2010). In the Cameroon estuary, *A. germinans* commonly produced a great number of seeds (Din *et al*., 2002b) which often establish in higher elevation/lower frequency of flooding areas (Hester *et al*., 2007; Pickens & Hester 2011). Seedlings of this genus may settle under the mother tree whenever they are trapped by pneumatophores (Proisy *et al*., 2009) and accordingly have a specific zonation (clumped distribution). In this case, the high intraspecific competition coupled with unfavorable edaphic conditions could sometimes lead to a high rate of seedling mortality (Din *et al*., 2002b). On the other hand, *Avicennia* seedlings may be greatly dispersed by tidal action (Clarke 1993; McKee 1995) and stranded in new areas where mud supply is enough to reduce prolonged substrate flooding (spatial randomness). Their higher salinity tolerance could competitively lead to an exclusion of other mangrove species in such elevated areas (Sobrado & Ewe 2006; Alleman & Hester 2011). The underlying mechanisms together might explain the observed variation in the spatial pattern of *A. germinans*.

Like many mangrove species (Tomlinson 1986; Matthijs *et al*., 1999; Satyanarayana *et al*., 2002), *A. germinans* often showed specific zonation in the Cameroon estuary. But trees of this species can be irregularly interspersed amongst *Rhizophora*. The cause of the observed structural feature was not directly examined here. Along with previous published data (Cardona-Olarte *et al*., 2006; Krauss *et al*., 2008), we assume that the spatial zoned pattern recorded in this study is partly driven by salinity ranges. This assumption is consistent with the findings of Din *et al*. (2002b) indicating that seedlings of *A. germinans* face a significant salt stress in their early growth stages. Additionally, the zonation of mangrove species is closely linked with a combination of other factors including soil properties, propagule survival, freeze tolerance, interspecific competition, variation in microtography and anthropogenic disturbances (Smith III 1987; Koch *et al*., 1997; Bosire *et al*., 2005b; Castaneda-Moya *et al*., 2006; Cunha-Lignon *et al*., 2009a; Luo *et al*., 2010; Pickens & Hester 2011). With regard to this, further investigations are necessary to better understand which of the aforesaid factors mainly influenced the structural development of the black mangrove *Avicennia germinans*.

7.5 CONCLUSION

Our results indicated that the spatial distribution of *A. germinans* is apparently random in the Cameroon estuary. This finding can be considered as a first step to describe the structural pattern of this best colonizer. In addition to this outcome, it is greatly important to develop a more complete characterization of the stand structure of *A. germinans*. We believe this objective can be achieved by analyzing endogenic organisation processes that occur within the growing environment of this species. Besides this need, there is still a lack of research information relating to spatial arrangement of trees found in these important coastal ecosystems. The lack is particularly critical given the fact that mangroves have been considered decreasing over a long period (Dahdouh-Guebas *et al*., 2004a; Duke *et al*., 2007; FAO 2007). More research, including modeling techniques, need to be focused on the description of a large range of pure, or mixed, mangrove stands. This would allow a better understanding of the effects of species composition and their architecture on the reliability of sampling distances and quadrants methods within mangrove forests.

ACKNOWLEDGEMENTS

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PLANCHE 8. Zone de mangroves périurbaines (périphérie de Douala, Cameroun) fortement anthropisée et considérée par certains locaux comme propriétée privée (lire la plaque).

PLATE 8. A peri-urban zone of mangrove forests (periphery of Douala, Cameroon) largely disturbed and considered by some local people as a private property (read the plate).

CHAPITRE 8

DISCUSSION GÉNÉRALE

Nous avons déjà mentionné dans l'introduction que la bonne compréhension des impacts directs et indirects de l'homme sur la structure de la végétation requiert l'utilisation d'une approche multidisciplinaire. Dans les études de cas formant la racine principale de cette dissertation, nous avons employé une diversité d'approches (chapitre 1, pages 29-31) qui nous ont permis d'analyser l'influence des activités anthropiques sur le développement structurelle des forêts de palétuviers à Kribi, l'embouchure du fleuve Nyong et l'estuaire du Cameroun. Les différentes conclusions émanant de chaque approche ont été clairement élucidées dans les résultats. Dans cette discussion générale, nous confrontons ces différents résultats. Nous poursuivons notre argumentation en abordant la question relative au devenir des forêts de mangroves au Cameroun.

8.1 INFORMATIONS ETHNOBOTANIQUES *VERSUS* DONNÉES DE TERRAIN

Au cours de notre première étude (chapitre 1), nous avons effectué des enquêtes ethnobotaniques dans certains marchés de Douala (Cameroun) spécialisés dans la vente du bois issu des forêts de mangroves. Nous y avons aussi associé les informations ethnobotaniques provenant des populations installées dans la Réserve Douala-Édéa. Il ressort de notre analyse que les souches de bois ayant un diamètre supérieur à 40 cm étaient plus commercialisées dans les marchés de Douala. D'autre part, nous avons noté que les populations résidant dans la Réserve de faune Douala-Édéa (chapitre 2) ainsi que celles installées à l'embouchure du fleuve Nyong et à Kribi (chapitre 3) exerçaient les activités de coupe sur les palétuviers jeunes et matures, mais sans toutefois procéder à la commercialisation. Nous avons également montré que le degré de prélèvement des ressources était considérable dans les zones périurbaines (chapitre 3, 4 et 5) comparé aux sites non périurbains (chapitre 6). Comme dans la plupart des côtes tropicales et subtropicales (FAO 2007; Walters *et al.*, 2008; Spalding *et al.*, 2010), nous avons remarqué dans l'ensemble de notre région d'étude que les différents produits forestiers collectés dans les mangroves étaient utilisés pour le bois de feu, la construction des maisons, le fumage du poisson, le bois d'œuvre, la confection des pirogues et pagaies, la teinture des vêtements et la phytothérapie. Par contre, l'utilisation du bois de mangroves pour la construction des foyers de fumage ("*banda*") de poissons n'a été observée qu'à l'estuaire du Cameroun (Nfotabong Atheull *et al.*, 2009). Au regard de tous ce qui précède, il serait intéressant de charactériser le type de structure forestière sur lesquelles s'effectuent régulièrement les coupes de bois.

Pour effectuer la caractérisation structurale de l'état *primaire* des mangroves anthropisées (chapitre 4), nous avons mesuré les paramètres structuraux des souches résiduelles et des arbres dans les forêts de palétuviers situées au voisinage de Douala. En utilisant l'indice de complexité, nous avons reconstruit la structure originelle de ces peuplements forestiers. Par la suite, nous avons utilisé le modèle individus-centré (modèle *KiWi*) développé par Berger &

Hildenbrandt (2000) pour attester quel scénario de coupe avait conduit à la structure actuelle des mangroves. Après l'interprétation des résultats issus de nos analyses, il s'ensuit qu'à Mboussa Essengue, les coupes s'effectuent généralement sur les forêts de palétuviers structurellement plus complexes (végétation dense à diamètre < 10 cm). Mais dans un autre site (Bois de Singes), on relève un équilibrage entre une coupe non sélective et une collecte fonction de la distribution des diamètres (préférence pour les arbres à diamètre compris entre 20-30 cm). Rappelons tout de même que le site échantillonné à Mboussa Essengue est adjacent aux habitations alors que celui investigué au Bois de Singes est situé dans une zone peu accessible.

En confrontant donc les résultats ethnobotaniques avec les données de terrain, il est tout à fait indéniable que les souches de bois prépondérantes dans les marchés (diamètre > 40 cm) (chapitre 2) sont le plus souvent collectées dans les endroits distincts des zones échantillonnées à Mboussa Essengue (0.33% de souches à diamètre > 40 cm) et au Bois de Singes (8.53% de souches à diamètre > 40 cm) (chapitre 5).

En effet pour des besoins culinaires et de construction des maisons, les populations établies à Mboussa Essengue (chapitre 5), Youpwe et Epassi (chapitre 3) ou dans la Réserve Douala- Édéa (chapitre 2) prélèvent généralement le bois dans les forêts de palétuviers jeunes et matures contiguës à leurs habitations et facilement accessibles à pied (Fig. 8.1 A).

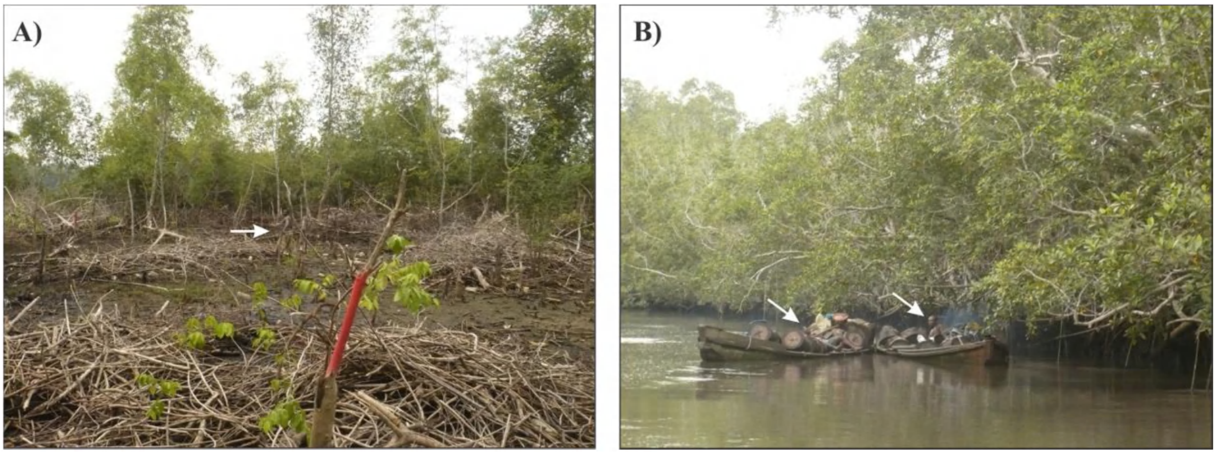

FIG. 8.1. Illustration des différents modes de collecte du bois de mangrove dans l'estuaire du Wouri (Douala, Cameroun). A) Perturbation de la structure des mangroves suite à une coupe d'arbres matures (diamètre n'excédant pas 30 cm) dans un site (Mboussa Essengue) facilement accessible à pied; B) Collecte de larges souches de bois dans une zone accessible uniquement par pirogue. Les flèches blanches sont orientées en direction des coupeurs.

Plusieurs régions côtières tropicales sont soumises à ce type d'activités anthropiques puisqu' une part considérable des communautés qu'elles hébergent sont caractérisées par une pauvreté chronique et une dépendance significative vis-à-vis des écosystèmes intertidales environnants (Kunstadter *et al.*, 1986; Walters 2005a; Hauff *et al.*, 2006; Walters *et al.*, 2008). Ainsi, afin d'accroître leur revenu mensuel (estimé à environ 98 €), les coupeurs impliqués dans la vente du bois de mangroves (chapitre 2) étendent leurs zones d'influence en effectuant communément les coupes dans les zones périurbaines (Din *et al.*, 2008; Nfotabong Atheull *et al.*, 2009) facilement accessibles par pirogues (Fig. 8.2 B). L'intensité des coupes est aussi fonction de la disponibilité en ressources forestières alternatives (FAO 2007). Ainsi, le degré de dégradation structurale des mangroves s'amoindrit lorsque celles-ci sont adjacentes à la forêt dense de terre ferme. C'est le cas par exemple des forêts de palétuviers situées à l'embouchure du fleuve Nyong et celles avoisiant le village Mpalla (Kribi).

8.2 PERCEPTION POPULATION LOCALES *VERSUS* ANALYSES DONNÉES NUMÉRIQUES

Les données numériques (photographies aériennes, images satellites) sont traditionnellement utilisées dans la classification du couvert végétal et sa composition spécifique, la caractérisation des paramètres bio-physique (indice de surface foliaire), structural (diamètre, hauteur) et fonctionnel (biomasse) ou la détection des changements environnementaux (Dahdouh-Guebas *et al.*, 2000b; Dahdouh-Guebas *et al.*, 2002; Fromard *et al.*, 2004; Simard *et al.*, 2006; Kovacs *et al.*, 2005; Proisy *et al.*, 2007; Neukermans *et al.*, 2008; Everitt *et al.*, 2010). Les images historiques telles que les photographies aériennes permettent de détecter les changements qui se sont déroulés bien avant la disponibilité des données satellitaires (Heumann 2011). Mais ces images d'archives peuvent parfois être très coûteuses (grande extension de la zone d'étude) voir même inaccessibles (restriction gouvernementale). Elles peuvent être aussi de mauvaise qualité, surtout dans les zones où la couverture nuageuse et l'absence d'éclairement rendent impossible toute forme de détection à distance pendant une grande partie de l'année (Bonn 1994). L'analyse de la perception des populations locales s'avère être une alternative permettant de qualifier certaines perturbations environnementales.

Cette approche perceptive a été récemment utilisée dans plusieurs travaux scientifiques abordant des thématiques différentes. A titre d'exemple, Kovacs (2000) en analysant la perception des pêcheurs établis aux voisinages de la lagune estuarienne de Teacapán-Agua Brava (Mexique), parvient à démontrer que l'ouverture d'un canal artificiel a conduit à une large perturbation (augmentation de la sédimentation, de la salinité et du flux d'eau) dans les mangroves de cette région. À l'estuaire du Cameroun, c'est la mise en place des hautes digues qui a occasionné des perturbations de la dynamique hydrologique dans certaines zones de mangroves périurbaines fortement anthropisées (chapitre 3). Dans les mangroves de Mpalla (Kribi), l'extension latérale des racines échasses de *Rhizophora* des berges vers le centre du lit mineur du fleuve a favorisée l'accumulation progressive des sédiments. Ce qui a entrainé une réduction de la voie d'alimentation d'eau.

Après avoir interviewé les agriculteurs installés dans la prairie d'Ombuga (Nord de la Namibie) et comparé les informations obtenues avec les résultats découlants d'une étude antérieure (*cf.* Klintenberg & Seely 2004) basée sur l'analyse (au niveau national) des indicateurs primaires (pression humaine, pression animale, pluviométrie et érosion), Klintenberg *et al*. (2007) rapportent pour leur part que c'est un complexe mixte de causes (réduction des zones de pâturage au Nord d'Ombuga, facilitation d'accès au site, disponibilité d'eau, augmentation du nombre d'animaux et pâturage intensif) qui est à l'origine de la forte dégradation des pâtures au Nord de la Namibie. En confrontant nos observations de terrain avec la perception des populations établies à l'intérieur ou aux environs des mangroves de l'estuaire du Cameroun (chapitre 3), nous sommes parvenus à dégager une conclusion similaire; bien que les facteurs dégradants soient différents.

En complément à ce type de comparaison, il est aussi nécessaire de confronter la perception des locaux avec les données scientifiques collectées sur le terrain. Rochet *et al*. (2008) explorent cet aspect en comparant les déclarations des pêcheurs interviewés dans le chenal Est anglais (situé entre le sud de la Grande Bretagne et le Nord de la France) avec les informations issues d'une base de données piscicole existante. Ils observent une synchronisation entre les deux types de données et suggèrent que les activités des chalutiers, l'extraction du sable, la pollution et le réchauffement de l'eau sont les principaux facteurs ayant conduit à une diminution de certaines espèces de poissons communément commercialisées. À l'embouchure du fleuve Nyong, les activités intenses des chalutiers à proximité des rivages sont également perçues comme causes principales de la baisse des quantités de poissons collectés à l'intérieur des mangroves.

En Australie, les risques d'un réchauffement global dû aux changements climatiques sont perçus par certains riverains qui déclarent d'ores et déjà les conséquences de ce phénomène sur leur vécu quotidien (Agho *et al*., 2010). Cet aspect n'a pas été exploré dans le cadre de cette étude.

Le long des côtes Est-africaines, les communautés côtières ont une faible perception des impacts et des risques liés au déversement d'eaux usées (domestique ou industrielles) dans les mangroves avoisinant leurs habitations (Crona *et al*., 2010). Par contre, certaines populations locales interviewées au Bois de Singes (Douala, Cameroun) perçoivent ce type d'activité anthropique comme facteur contribuant à la dégradation des forêts de palétuviers. Mais, leur perception ne corrobore pas avec nos observations de terrain.

Lors de notre seconde étude (chapitre 2), nous avons observé que la perception du degré de dégradation des forêts de palétuviers n'était pas la même à l'estuaire du Cameroun qu'à Kribi (Mpalla) et l'embouchure du fleuve Nyong. Les mangroves de l'estuaire du Cameroon étant perçues comme les plus dégradées. Dans l'optique de convaincre les décideurs locaux que les perturbations structurales sont effectives dans les écosystèmes de mangroves, certains auteurs suggèrent que la prochaine étape devrait consister à vérifier la perception des locaux par le biais d'une comparaison avec les données quantitatives (Kovacs 2000; Conchedda *et al*., 2011). Du fait de l'indisponibilité de séries diachroniques d'images satellitaires ou de photographies aériennes, nous n'avons pas eu la possibilité d'évaluer la dynamique spatio-temporelle des mangroves non périurbaines situées dans les régions du Littoral et Sud-Cameroun. Néanmoins, nous avons, sur trois décennies, caractérisé quantitativement le couvert végétal des mangroves avoisinant la ville de Douala (Cameroun). Nos résultats (Chapitre 3) ont montré que 53,16 % de mangroves périurbaines avaient été perdus sur une période de 35 ans. Ce qui corrobore avec la perception des communautés locales (Chapitre 2). Ce déclin considérable du couvert végétal des mangroves n'est pas une singularité camerounaise mais concerne bon nombre de pays tropicaux hébergeant sur leurs côtes les forêts de palétuviers (Dahdouh-Guebas *et al.*, 2004a; Duke *et al.*, 2007; FAO 2007; Polidoro *et al.*, 2010; Spalding *et al.*, 2010).

La matrice de transition est souvent utilisée pour expliquer les processus de transformation spatiale du paysage (Turner 1989; Schlaepfer 2002). Elle ne prend pas en considération les facteurs responsables de la dégradation d'un écosystème mais se base uniquement sur la typologie de ses différentes composantes entre deux périodes successives. Bien que souvent organisée differemment, les informations qu'elle contient sont similaires à celles reprises dans le Tableau 4.1.

8.3 PERTURBATION FONCTION DE LA DISTANCE VIS-À-VIS DE LA ZONE URBAINE

La perte du couvert végétal des mangroves périurbaines peut être couplée à une réduction des ressources forestières les plus exploitées par les communautés côtières. En ce moment, les prélèvements incontrolés de bois peuvent s'orienter vers des zones non périurbaines et occasionnées à nouveau une exploitation abusive des ressources restantes (Hernández Cornejo *et al.*, 2005). Au regard de cette assertion, nous avons avons formulé la question de savoir si la structure des mangroves non périurbaines était relativement moins perturbée par les activités anthropiques (Chapitre 5). Pour répondre à cette question, nous avons à l'aide d'une image QuickBird (année 2001) effectué une analyse texturale des paramètres de structure d'une mangrove non périurbaine située à environ 9 km de Douala (Cameroun). Les résultats obtenus ont montré que la texture hétérogène de la canopée n'était liée ni aux coupes intenses, ni ou aux différentes propriétés édaphiques, mais reflétait plutôt l'historique passé du site investigué. En corollaire, il s'est avéré que les perturbations anthropiques étaient relativement faibles dans les zones non périurbaines.

Dans le bassin de Douala, les précipitations sont très importantes et avoisinent 4000 mm par an (Lieth *et al.*, 1999). Comme conséquence, les nuages épais et la brume légère obscurcissent fréquemment l'atmosphère, réduisant ainsi considérablement la sensibilité des capteurs qui enregistrent dans les longueurs d'ondes du visible et de l'infrarouge (Wilkie 1994). Au regard de ce qui précède, on peut donc s'attendre à une faible disponibilité d'images satellitaires dans la région. Durant nos travaux, nous avons été confrontés à une rareté d'images satellitaires dépourvues de couverture nuageuse. Ceci nous a astreints à utiliser une image enregistrée à une période différente de celle à laquelle nous avons effectué nos relevés de terrain. Le model FORMAN proposé par Chen & Twilley (1998) nous permis de corriger les écarts suite à un ajustement de diamètre d'arbres. Pour effectuer cette correction, nous avons considéré un scénario de croissance optimale.

Les facteurs environnementaux tels que la salinité, la disponibilité relative en nutriments (N et P), la compétition pour l'espace et la lumière influencent très souvent la croissance des palétuviers (Chen & Twilley 1998). L'omission des facteurs correctifs liés à ces composantes environnementales peut conduire à une surestimation des diamètres ajustés. Dans notre site d'étude, le facteur correctif de la salinité aurait été peu important à cause de la forte dilution d'eau marine aucours de l'année (9 mois de saison pluvieuse). Le faible taux de N (rapport C/N élevé) observé dans l'ensemble des trois types forestiers (Table 6.2) pourrait être due à une augmentation de sa réabsorption avant l'abscission ou à une forte minéralisation (Inoue *et al.*, 2011). Ainsi, la prise en compte du facteur correctif de N n'aurait pas réduit de manière significative les valeurs de diamètres ajustés. Le taux de phosphore et la compétition pour l'espace et la lumière n'ont pas été estimé dans le cadre de cette recherche. En corollaire, l'influence de leurs facteurs correctifs sur les valeurs de diamètres ajustés ne peut être évaluée.

L'équation allométrique commune développée par Komiyama *et al.* (2005) a été utilisée pour inférer les biomasses à partir des diamètres ajustés. Les relations entre diamètres et biomasses auraient pu être établies localement, en utilisant par exemple les troncs de palétuviers abattus. Mais, l'équation allométrique employée dans cette étude ne tient pas compte des spécificités des sites échantillonnés (Komiyama *et al.*, 2008). Elle est plutôt dépendante de la densité du bois qui varie très souvent entre différentes espèces. Ce paramètre structural a été mesuré localement. L'utilisation de l'équation allométrique développée par Chave *et al.* (2005) pour convertir les valeurs de diamètres en biomasses aurait produit les résultats presque similaires à ceux obtenus dans ce travail. Les deux équations allométriques ne présentant qu'une faible différence au niveau de leurs facteurs multiplicatifs ($W_{top} = 0.251 pD_{130}{}^{2.46}$ (Komiyama *et al.*, 2005); $W_{top} = 0.168 pD_{130}{}^{2.47}$ (Chave *et al.*, 2005)).

Il est important de rappeler qu'afin d'assurer une bonne correspondance entre nos données de terrain (collectées en 2009) et les indices de textures (obtenus après analyse texturale de l'image QuickBird enregistrée en 2001), nous avons établi les parcelles uniquement sur les zones peu anthropisées (Chapitre 5). Lors de cette phase d'échantillonnage (en 2009), nous avons remarqué que la structure de la végétation des mangroves présentait quelques signes d'anthropisation. Au sud-est de notre zone d'étude, nous avons également observé une végétation décadente et clairsemée similaire à celle décrite en Guyane française par Proisy *et al*. (2007).

Malgré la forte fréquence de couvertures nuageuses dans notre zone d'étude, nos investigations nous ont permis tout de même d'obtenir quelles portions d'images peu ennuagées montrant que les zones de végétation précédemment peu perturbées (Fig. 8.2 A1 & B1, 2001) présentaient déjà quelques trouées artificielles quatre années plus tard (Fig. 8.2 A2 & B2, 2005). Toutefois, le niveau de perturbation reste de faible amplitude lorsqu'on effectue une comparaison avec la zone périurbaine (chapitres 3, 4 et 5 *versus* chapitre 6). Ainsi, nous devons toujours considérer que les mangroves non périurbaines sont peu anthropisées.

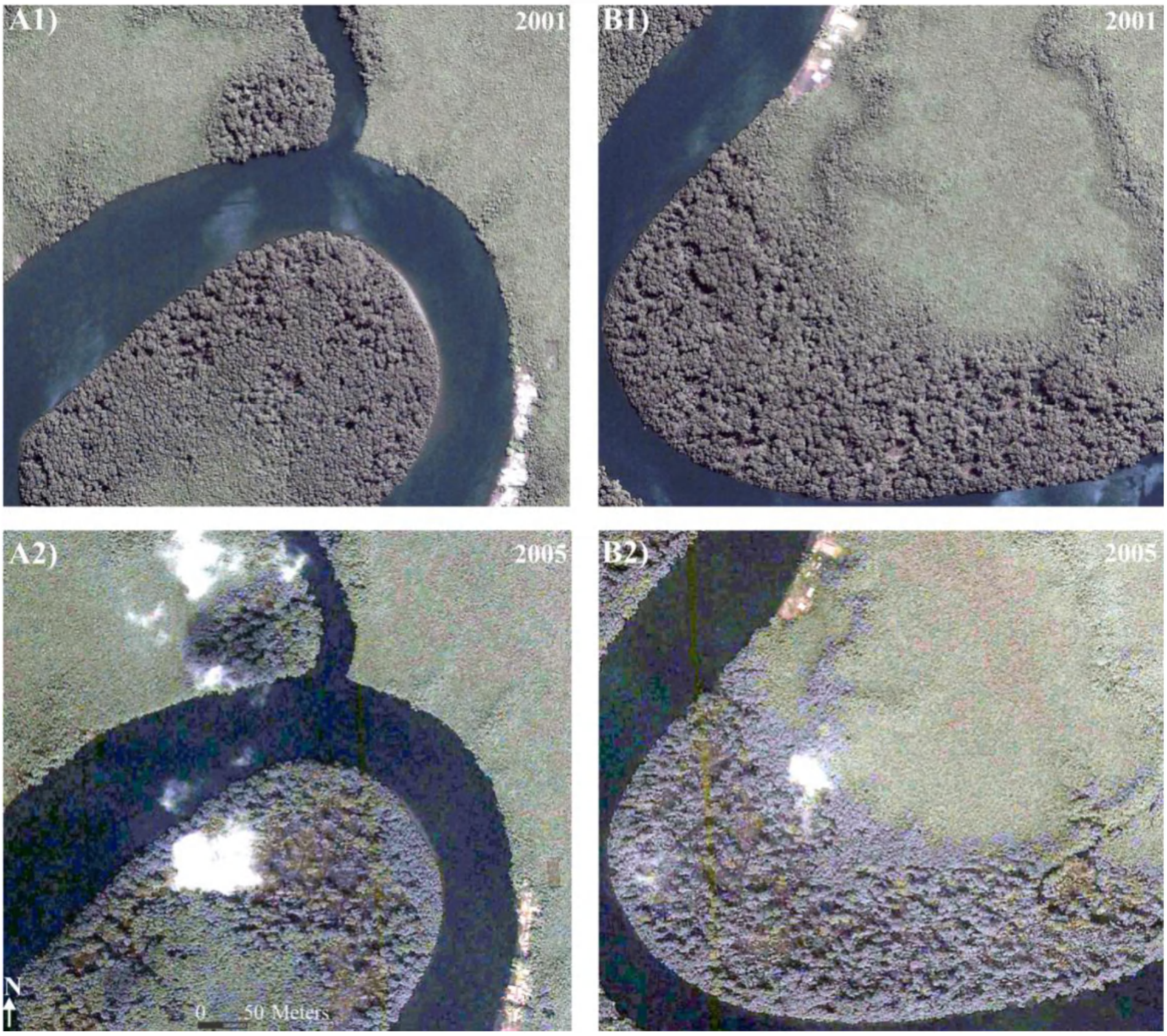

FIG. 8.2 Séries diachroniques d'images satellitaires à très haute résolution (~1 m) prises au niveau de la crique Lefèvre (3° 58'N - 9° 38'E). On observe tout d'abord une mangrove à structure très peu anthropisée (A1 & B1, 2001) qui sous l'effet de quelques coupes commence à se dégradér (A2 & B2). Les gaps présents sur les images A1 & B1 correspondent en grande partie aux zones à chablis alors que la plupart des trouées visibles sur les images A2 et B2 (2005) sont issues des activités de coupe. Les futaies géantes à *Rhizophora racemosa* sont dominantes sur les côtés convexes. La végétation basse à port nain et tortueux qui colonise les rives concaves et les zones internes de la forêt est composée d'un mixage de *R. racemosa et R. harrisonii*. Les zones blanches bordant la rive concave représentent les campements de pêcheurs. L'échelle et la direction Nord sont valables pour toutes les images satellitaires. Images © QuickBird.

D'après nos propres observations sur le terrain, nous avons aussi constaté dans la zone de Kribi que le degré de dégradation des mangroves était fonction de leur proximité vis-à-vis de la zone urbaine. A ce titre, nous avons effectué plusieurs photographies des zones de mangroves fortement anthropisées à Nziou, localité située à 2 km du centre urbain de Kribi. Afin de matérialiser le faible niveau de perturbation structurale des mangroves non périurbaines, nous avons aussi fait des prises de vue à Mpalla, village distant de Nziou d'environ 3 km. Deux cas d'exemples concrets montrant ces différents états de mangroves sont illustrés à la Figure 8.3 A & B.

FIG. 8.3 Vue de la végétation des mangroves dans deux localités de Kribi (Sud-Cameroun). On remarque dans la localité de Nziou (A) que certaines zones précédemment couvertes de mangrove ont été remplacées par les habitations modernes (une maison est d'ailleurs visible à l'arrière des *Rhizophora* spp.). Aussi, on observe sur cette même photo de nombreuses graminées ainsi que des palmiers et bananiers. Contrairement au cas précédent, l'on note une faible anthropisation des mangroves de Mpalla (B). Ces dernières sont contigües à la forêt dense de terre ferme (voir l'arrière de la Figure 8.3 B).

8.4 ESPÈCES CLIMAX *VERSUS* ESPÈCE PIONNIÈRE

Plusieurs travaux réalisés dans les mangroves au Cameroun mentionnent que *Rhizophora* spp. (palétuviers rouges) est dominante (Din 1993; Abata 1994; Din 2001; Baltzer *et al.*, 2001; Van Campo & Bengo 2004; Ajonina 2008). En accord avec les études précédentes (Feka 2005; Feka & Manzano 2008; Din *et al*., 2008; Feka *et al*., 2009), nos résultats ethnobotaniques indiquent que ces palétuviers rouges (espèces climax) sont fort commercialisés ou directement utilisés dans les ménages pour des besoins de subsistance (Chapitre 1 & 2). Notons que les activités de coupes sont aussi exercées sur la seconde espèce abondante qu'est *Avicennia germinans* (palétuviers noirs) (espèce pionnière), mais à de faibles fréquences (Nfotabong Atheull *et al*., 2009).

Nous rapportons dans notre seconde étude qu'une bonne partie de palétuviers rouges abattus était abandonnée sur le terrain. Par la même occasion, nous indiquons que les amas de branches délaissés pourraient perturber considérablement la dispersion des propagules de *Rhizophora* qui s'avèrent plus grands que ceux d'*A. germinans* (Chapitre 2, discussion). Ce qui laisse croire que ces zones perturbées ont de fortes chances d'être colonisées par les propagules d'*A. germinans* qui sont très souvent dispersés sur de longues distances (Rabinowitz 1978; Dodd *et al*., 2000). Mais, Din *et al*. (2002b) précisent que dans l'estuaire du Wouri (Douala-Cameroun), les graines de cette espèce s'établissent généralement à côté de la plante mère. Ce qui provoque une compétition intraspécifique élevée qui conduit le plus souvent à une forte mortalité des plantes juvéniles.

La zonation des espèces dans l'aire atlantique des mangroves (entre Antilles, Guyane, Brésil et Afrique de l'Ouest par exemple), peut être en *apparence* très différente voir contradictoire, dépendante également du type de mangroves (côtier, de lagune ou estuarien) (Bertrand 1999; Fromard *et al*., 2004; Cunha-Lignon *et al*., 2009a, b; Anthony *et al*., 2010). Le rôle pionnier *versus* climax de chaque espèce est aussi dépendant de ces dernières notions. Après avoir analysé la distribution spatiale de ce palétuvier noir dans trois stations monospécifiques situées à l'estuaire du Cameroun, nous avons montré que la structure spatiale d'*A. germinans* était aléatoire sur une moitié des parcelles échantillonnées et agregée à certaines distances pour l'autre moitié (Chapitre 6). Il aurait été judicieux de considérer les parcelles de plus grande taille (parcelle de 1 ha par site) pour l'analyse de ces structures spatiales ponctuelles. Mais, l'environnement rude (substrat instable, racines échasses denses et enchevêtrées, présence de chenaux secondaires, etc…) des mangroves a rendu la mise en place de ce type de dispositif difficile.

Dans les mangroves camerounaises, *A. germinans* ne forme pas toujours une station pure mais peut aussi côtoyer les espèces comme *Rhizophora racemosa*, *R. harrisonii*, *R. mangle*, *Nypa fruticans*, *Laguncularia racemosa*, *Guibourtia demensei* et *Conocarpus erectus*. Lorsque la station mixte est non perturbée et composée à la fois de palétuviers noirs sénescents et de palétuviers rouges matures, on observe une prépondérance des propagules de *Rhizophora* spp. sur un rayon d'environ 4 m autour de l'arbre parental (Fig. 8.4 A). En cas de coupe d'arbres pourvoyeurs de propagules, on assiste non seulement à une destruction de juvéniles préétablis mais aussi à une réduction de leur fréquence d'implantation (Fig. 8.4 B).

L'enroulement progressif de gros morceaux de bois cylindriques peut conduire à une consolidation du substrat. Ce dernier peut donc s'assécher plus rapidement que celui rencontré dans les zones peu impactées (Rajkaran *et al*., 2010). La recolonisation de peuplement dans ces milieux perturbés dépendra certainement de la capacité d'espèces climax (*Rhizophora* spp.)/pionnières (*A. germinans*) à produire de nouveaux propagules (Borise *et al*., 2006; Rajkaran *et al*., 2010). Lorsque les arbres sur pied sont majoritairement des palétuviers noirs, la revégétalisation des zones anthropisées possédant moins d'éléments enchevêtrés pourra aussi se faire suite à un approvisionnement des propagules (majoritairement celles de *Rhizophora*) par la marée. Le succès de cette dernière est indéniablement fonction du degré de perturbation du substrat.

FIG. 8.4 (A) Prépondérance des propagules de *Rhizophora* spp. dans une station mixte composée de palétuviers noirs sénescents (larges troncs) et de palétuviers rouges matures (présence de racines échasses). La compétition intraspécifique élevée (forte densité d'individus) couplée à la prédation (par les crabes, gastéropodes, etc…) et au faible taux d'ensoleillement (canopée fermée) conduira certainement à la disparition d'une part importance de ces propagules. (B) Rareté des propagules dans une station mixte fortement anthropisée. On observe également sur cette photo de nombreuses souches de bois (issues de la coupe des *Rhizophora*) abandonnées. Certaines souches ont d'ailleurs déjà amorcées le processus de décomposition.

8.5 PERTURBATIONS DE LA STRUCTURE DU SOL

Les activités anthropiques n'affectent pas seulement la végétation des mangroves mais peuvent occasionner aussi des perturbations au niveau de la structure voir même la nature du substrat. A titre d'exemple, Rajkaran *et al*. (2010) soulignent que dans l'estuaire de Mngazana

(Cape-Est, Afrique du Sud), les sédiments des zones de mangroves dénudées (suite aux coupes excessives) présentaient des caractéristiques différentes comparées à ceux prélevés dans des sites peu anthropisés et encore végétalisés. Bosire *et al.* (2003) ont aussi trouvé des résultats similaires dans les mangroves de la Baie de Gazi (Kenya), où ils démontrent que le taux de matière organique dans les zones mixtes à *Avicennia* et *Rhizophora* était dix fois supérieur à celui des sols dépourvus de végétation.

Dans le cadre de nos recherches, ce type de comparaison n'a malheureusement pas fait l'objet d'études approfondies même si nous nous sommes attelés à effectuer l'analyse granulométrique des sédiments prélevés dans les sites peu perturbés (Chapitre 5). Ce complément écologique pourrait faire l'objet de nos futurs travaux de recherches.

Nous avons réalisé plusieurs visites de terrain sur les zones fortement dévégétalisées. Sur la base des observations réalisées aux environs de Douala (Cameroun), nous avons remarqué que les activités d'endiguement (pour des besoins de construction des habitations) (Fig. 8.5 A) et d'extraction de sable et graviers (Fig. 8.5 B) entraînaient une modification considérable de la structure du sol. Ce qui peut entrainer non seulement la perte de certaines fonctions essentielles du substrat des mangroves (lieu d'établissement des propagules, habitat, sources nutritionnelles, zone de reproduction des poissons et crustacés, protection côtière) mais aussi de plusieurs espèces de la faune aquatique.

FIG. 8.5 (A) Excavation des sédiments dans une zone de mangroves périurbaines (périphéries de Douala (Cameroun)) ayant fait l'objet de coupes intenses. Les blocs de sédiments forés seront entreposés sur une zone de mangroves dévégétalisée. La hauteur de l'entrepôt atteint parfois un mètre. Ceci permet d'éviter les entrées d'eau dans les habitations surtout en période de grande marée de vives eaux). (B) Extraction du sable le long des berges d'un chenal assurant l'alimentation des mangroves en eau. Une bonne partie des palétuviers ainsi que des sédiments ont été enlevés. Avant le début de l'extraction, la pirogue est immobilisée à l'aide de deux petites tiges issues de la coupe des *Rhizophora* spp. Le sable boueux collecté sera par la suite lavé et tamisé afin de soustraire les sédiments, éléments grossiers et certains débris végétaux (surtout les racines mortes).

Si l'on se limite seulement au cas des crabes à terrier, leur perte pourrait dans un futur proche provoquer des changements dans l'environnement des sédiments puisque ces crustacés décapodes influencent le cycle des nutriments, l'aération et le drainage des sols de mangroves (Kathiresan & Bingham 2001). En plus, le déplacement des blocs de sédiment consolidés et leur entassement à des endroits devant servir ultérieurement à l'implantation des habitations favoriseront certainement l'érosion côtière.

8.6 ESQUISSE DE LA GESTION ACTUELLE DES MANGROVES AU CAMEROUN

Les activités des différentes entités gouvernementales impliquées dans la gestion des écosystèmes de mangroves ne sont pas coordonnées. En corollaire, il s'ensuit des conflits entre les différents organes étatiques qui se sont vus conférer des compétences en matière de gestion des écosystèmes marins et côtiers (MINEF 1996); il s'agit bien évidemment du:

1. Ministère des Forêts et de la Faune (MINFOF) qui veille à la gestion rationnelle des ressources forestières et faunistiques.
2. Ministère de l'Environnement et de la Protection de la Nature (MINEP) qui est en charge du suivi de la conservation et de la protection des ressources naturelles, des évaluations et inspections environnementales, de la sensibilisation et du suivi des projets structurants.
3. Ministère de l'Elevage, des Pêches et des Industries Animales (MINEPIA) qui élabore, met en œuvre et évalue la politique de l'État en matière d'élevage, de pêches et de développement harmonieux des industries animales.
4. Ministère des Mines, de l'Eau et de l'Energie (MINMEE) qui assure la gestion de l'eau, des hydrocarbures et minerais marins. Il est assisté dans sa mission par la Société National des Hydrocarbures.
5. Ministère des Travaux Publics (MINTP) qui dans le domaine maritime coordonne la réalisation des travaux portuaires ou d'infrastructures marines (construction des pipelines, d'oléoducs, des plateformes pétrolières et gazières, etc...).
6. Ministère des Transports (MINTRANS) dont la direction de la Marine Marchande sécurise les déplacements dans les fleuves et la mer.
7. Ministère du Tourisme (MINTOUR) qui est en charge de la promotion du tourisme dans les zones côtières.

Pour obtenir des solutions effectives pouvant conduire à une gestion durable des écosystèmes de mangroves, nous devrons transcender ces différents conflits institutionnels (Farley *et al.*, 2005, 2010). Cela passe indéniablement par une bonne définition des rôles de chaque acteur de manière à éviter tout chevauchement de compétences.

Du point de vue écologique, biologique et économique, la mise en place des modalités de gestion efficiente des écosystèmes de mangroves n'est pas évidente et nécessite dès lors des interventions multidisciplinaires (Farnsworth 2004; Datta *et al.*, 2010). En effet, une collaboration étroite doit être établie entre les organes étatiques, les institutions académiques, les Organisations Non Gouvernementales (ONG) et les communautés locales (Farley *et al.*, 2010). A notre connaissance, la mise en place de ce type de coopération n'a pas encore réellement pris effet au Cameroun. Du 4-5 Mai 2010, un symposium pan-africain sur la mangrove et les changements climatiques s'était tenu à Douala (Cameroun). Paradoxalement, nous n'avons noté aucune participation d'un représentant des communautés locales. Pourtant ces derniers étaient le plus souvent cités comme responsable de la dégradation des structures de mangroves. L'implication des locaux dans ce type de forum constituera un moyen de transformer nos connaissances en action (Datta *et al.*, 2010; Farley *et al.*, 2010).

Dans cette optique, certaines ONG telles que le Réseau camerounais pour la Conservation des écosystèmes de Mangrove (RCM), le Comité Pilotage pour la Conservation et la Valorisation des Mangroves de Mouanko (COPCVAM), la "*Cameroon Environmental Watch*" (CEW), "*Cameroon Mangrove Network*" (CMN) et "*Cameroon Wildlife Conservation Society*" (CWCS) prônent diverses actions de sensibilisation, d'amélioration des fumoirs de poissons et de régénérations (plantation des propagules). En addition à tous cela, un projet de suivi de la vitalité des mangroves de Kribi a été lancé en 2008 par la Société Nationale des Hydrocarbures (SNH) et est déjà en cours d'implémentation.

8.7 QUEL FUTUR POUR LES MANGROVES AU CAMEROUN?

8.7.1 *Mangroves périurbaines*

Comme dans les Philippines (Farley *et al.*, 2010), certaines zones de mangroves périurbaines camerounaises (domaine étatique) sont considérées par les riverains comme des propriétés privées (Planche 8, page 149). Ces derniers peuvent à tout moment procéder au bornage et à leur commercialisation pour des besoins de lotissement.

Aussi bien à l'estuaire du Cameroun qu'à Kribi (Nziou), nos résultats démontrent l'existence d'une perturbation considérable des structures de la végétation des palétuviers périurbains. L'urbanisation anarchique (Din & Blasco 1998; Din *et al.*, 2001b) et l'extraction du sable et des graviers (activités se déroulant uniquement dans les mangroves avoisinant la ville de Douala) apparaissent comme les principaux facteurs dégradants car elles nécessitent non seulement la coupe complète des palétuviers sur de grandes étendues mais aussi l'altération profonde des sédiments. L'implantation des habitations sur les zones dévégétalisées ainsi que l'excavation des sédiments dénudés sont en perpétuel progression. Ce qui rend par conséquent difficile toute possibilité de revégétalisation et de restructuration.

Dans l'estuaire du Cameroun, l'arrière-mangrove périurbaine est aussi régulièrement utilisée pour l'agriculture. Après avoir initié une étude sur la régénération spatio-temporelle des propagules de *Rhizophora* spp., nous n'avons pu échantilloné que pendant six mois.

L'entièreté de nos parcelles permanentes (établies à l'intérieur des mangroves du Bois Singes) ayant été endommagé et remplacé par les cultures vivrières (maïs, haricot, bananier, légumes verts, canne à sucre et palmier à huile). Au vue de tout ce qui précède, il est donc fort probable que l'on assiste dans les années à venir à la disparition complète des palétuviers avoisinant les zones urbaines.

8.7. 2 *Mangroves non périurbaines*

La structuration de la végétation des mangroves suite aux activités de construction d'habitations, d'extraction minières (sable et graviers) et agricoles n'est pas effective en zones non périurbaines. Ici, le facteur susceptible de structurer le couvert végétal est la coupe des palétuviers. Dans l'estuaire du Cameroun, la chute des grands arbres provoque la destruction de nombreuses plantes (juvéniles et adultes) qui croissent dans leur environnement immédiat. Les trouées artificielles (pourvues d'éléments enchevêtrés) qui en découlent sont le plus souvent entourées d'arbres matures. Ces derniers produisent régulièrement d'importantes quantités de propagules (Din 2001). Ce qui accroît considérablement les possibilités de revégétalisation de ces zones anthropisées.

Malgré cette capacité de régénération, les mangroves non périurbaines situées dans l'estuaire du Cameroun, l'embouchure du fleuve Nyong et Kribi seront confrontées dans l'avenir aux perturbations provenant des activités d'exploration (prospection sismique pour identifier les réserves potentielles de pétroles) et d'exploitation pétrolières (MINEF 1996; MINEP 2004). La dévégétalisation de ces forêts intertidales résultant de la délinéation sismique laissera le sol dénudé susceptible d'être érodé par les mouvements de vague (Osuji *et al.*, 2010). La perturbation de la structure des mangroves sera inéluctable puisque les phases d'exploration sismiques (positionnement des câbles) nécessitent très souvent la coupe d'arbres sur pied (Osuji *et al.*, 2007). Comme il a été démontré au Nigéria, le recouvrement des zones perturbées pourra nécessiter environ trois années (Aston-Jones 1988).

8.7.3 *Crédit carbone pour la conservation des mangroves*

Le stock carboné des mangroves est supérieur à celui des autres domaines forestiers majeurs (forêts boréale, tempérée et équatoriale) (Donato *et al.*, 2011). Plusieurs travaux scientifiques ont démontré que la grande proportion de réserves en carbone de ces écosystèmes littoraux tropicaux et subtropicaux est stockée dans les sédiments (Bouillon *et* 2003; Khan *et al.*, 2007; Kauffman *et al.*, 2011; Donato *et al.*, 2011). Nos résultats corroborent avec ces observations. En effet, nous avons observé que le stock moyen de carbone contenu dans le sol et la végétation des parcelles échantillonnées à l'estuaire du Cameroun correspondait respectivement à 241[†] et 102 t ha^{-1}. Le taux élevé de carbone dans ces sédiments estuariens est probablement lié à leur forte richesse en matière organique (Tableau 6.2). Le stock carboné global des mangroves étudiées ici aurait été encore plus important si l'on avait pris en compte la part contenue dans les racines souteraines. Au regard de la carte de distribution des stocks carbonés (Fig. 6.9), l'on remarque que les réserves en carbones des parties aériennes des peuplements de palétuviers situés à l'estuaire du Cameroun peuvent dans certaines zones avoisiner 300 t ha^{-1}. Ces zones à hautes futaies constituent de véritables aires d'accrétion qui sont vraisemblablement pourvues d'important stock de carbone tourbeux. Un scénario de coupes intenses dans ces zones de mangroves – en affectant la biomasse aérienne forestière – entrainerait l'émission significative de CO_2 suite à l'oxidation du carbone contenu dans ces tourbières (Eong 1993; Sjöling *et al.*, 2005; Granek & Ruttenberg 2008; Lovelock *et al.*, 2011).

En se référant à l'ensemble des observations ci-dessus, l'on peut inéluctablement affirmer que les écosystèmes de mangroves, en particulier ceux situés le long des côtes camerounaises, jouent un rôle important dans le cycle global du carbone. En constituant d'importants réservoirs de carbone, c'est écosystèmes côtiers participent significativement à la réduction de la concentration de gaz à effet de serre dans l'atmosphère terrestre. Ce qui permet d'atténuer les effets néfastes que peuvent occasionner les changements climatiques. L'une des conséquences de ces phénomènes de réchauffement climatique est l'augmentation du niveau de la mer. Mais, l'on reste encore peu éclairé sur la manière donc cela pourrait effecter les stocks carbonés des écosystèmes de mangroves (Kauffman *et al.*, 2011).

Une stratégie incitative visant à réduire les émissions de dioxide de carbone (CO_2) issues de la déforestation et de la dégradation des forêts de mangroves serait celle de crédits carbone (Myers 2008). De telles ressources financières faciliteront la mise en place des micro-projets locaux visant à répondre aux besoins de subsistances des riverains. Ceci réduirait leur dépendance vis-à-vis des écosystèmes de mangroves et contribuerait à leur conservation.

[†] Les valeurs du taux de carbone organique des sols, exprimées en pourcentage (voir Tableau 6.2), ont été converties en tonnes par hectare à l'aide des facteurs de conversion suivants: 1 ppm = 0,0001% et 1 ppm × 2,24/1000 = 1 tonne par hectare

CHAPITRE 9

CONCLUSIONS ET PERSPECTIVES

Cette étude nous a permis, d'une part, d'améliorer nos connaissances sur les diverses utilisations des produits issus des forêts de mangroves et, d'autre part, de comprendre les effets des activités anthropiques sur la structure de la végétation de ces écosystèmes littoraux tropicaux.

Au regard des résultats obtenus, l'on peut aussitôt conclure qu'à l'estuaire du Cameroun, les populations locales collectent de façon notable le bois dans les forêts de mangroves (Chapitre 1 & 2). Ce bois est le plus souvent à usage commerciale ou domestique. Les populations locales qui s'en procurent l'utilisent principalement comme source d'énergie et/ou matériel de construction. Bien que l'utilisation du bois des palétuviers soit très accentuée à l'estuaire du Cameroun, elle reste cependant de faible importance à Kribi (Mpalla) et l'embouchure du fleuve Nyong. En fait, les riverains de ces deux dernières localités prélèvent quotidiennement le bois de chauffe directement dans la forêt humide dense de terre ferme qui avoisine les mangroves.

Nous avons observé que les communautés côtières établies à l'estuaire du Cameroun percevaient les forêts de mangroves périurbaines comme des écosystèmes fortement dégradés et donc en déclin. Par contre, les populations installées à Kribi et à l'embouchure du fleuve Nyong ont une opinion qui est plutôt favorable à une faible dégradation des mangroves.

En couplant la perception des résidants locaux aux observations de terrain, nous sommes parvenus à conclure que c'est un complexe mixte de causes (coupe excessive, urbanisation anarchique, extraction du sable et des graviers, construction des digues, création de corridors) qui est à l'origine de la forte dégradation structurelle du couvert végétal des mangroves périurbaines (estuaire du Cameroun). Les perturbations anthropiques ne se limitent pas seulement à la végétation mais affectent également la structure des sédiments.

À l'issu de l'analyse de série diachronique de photographies aériennes, nous avons montré qu'entre 1974 et 2009, 53,16% de la superficie des mangroves périurbaines avait été perdue dans l'estuaire du Wouri (Douala, Cameroun) (Chapitre 3). La perte de ces mangroves étant principalement due à leur conversion en infrastructures routières, en zones agricoles et en habitations. En outre, dans les zones de mangroves facilement accessibles et faisant uniquement l'objet de coupes intenses (Mboussa Essengue), nous avons observé que la collecte du bois s'effectuait habituellement sur une végétation structurellement plus complexe (petits arbres à densité élevée) (Chapitre 4). Mais lorsque la forêt de palétuviers devenait relativement peu accessible (Bois de Singes), les activités de coupe étaient orientées vers une végétation structurellement plus développée (grands arbres à densité faible).

Nous rapportons également dans notre travail que la structure des mangroves non périurbaines bien qu'étant très peu anthropisée en 2001 (Chapitre 5), présentait des perturbations modérées quatre années plus tard (en 2005). La revégétalisation des trouées artificielles pourvues d'éléments enchevêtrés (tiges, branches et troncs abandonnés sur les lieux de coupes) dépend indéniablement de la capacité de dispersion de propagules. Naturellement, la contribution de l'espèce la plus abondante (*Rhizophora* spp.) dans ce processus de recouvrement des zones perturbées est considérable. Mais, *Avicennia germinans* (seconde espèce dominante) peut aussi jouer un rôle non négligeable lors du recouvrement des trouées artificielles. En effet, nos résultats ont montré que cette espèce présentait une structure spatiale aléatoire sur une moitié des parcelles échantillonnées et agregée à certaines distances pour l'autre moitié (Chapitre 6). De plus, les propagules de cette espèce, qui sont de petites tailles, ont la capacité de flotter pendant une longue période et, en corollaire, d'être dispersées sur de longues distances.

En somme, nous pouvons déduire de cette étude l'existence d'une faible perturbation anthropique de la structure des mangroves non périurbaines et d'une forte anthropisation structurelle des forêts de mangroves périurbaines.

Ainsi, sur la base de nos résultats et des expériences de terrain, la gestion durable des écosystèmes de mangroves périurbaines nécessite:

1. La bonne maîtrise de l'exode rural et la prise en compte des besoins locaux en ce qui concerne les lotissements (zones périurbaines): l'arrivée de nombreux migrants dans la ville de Douala a récemment (entre 2009-2010) accéléré l'urbanisation anarchique qui s'est faite au détriment des mangroves.
2. Une réelle coopération avec les communautés locales impliquées dans l'exploitation abusive des écosystèmes de mangroves: Celle-ci passe sans doute par une offre alternative en matière d'énergie (utilisation du gaz), de matériaux de construction (bâtir en matériaux définitif) et d'emploi (promouvoir des microprojets locaux). Les crédits carbones peuvent constitués de véritables ressources financières.
3. La plantation des propagules dans les zones de mangroves périurbaines fortement anthropisées mais dont le substrat reste peu perturbé (faible endiguement).
4. Une bonne exploitation des zones dévégétalisées ne pouvant plus se recouvrir naturellement (du fait de l'excavation des sédiments et de l'extraction du sable). Celles-ci peuvent être endiguées et utilisées pour l'aquaculture.

La gestion rationnelle des mangroves non périurbaines quant à elle pourra se faire par la mise en application des mesures stratégiques proposées par MINEF (1996) et MINEP (2004).

Il s'agit:

1. D'identifier les différentes zones bio-écologiques et leurs caractéristiques.
2. D'élaborer une fiche technique d'exploitation des essences qui mentionne le diamètre des arbres à l'abattage, le rythme de réalisation des éclaircies dans les nouvelles plantations de palétuviers, la période de rotation des exploitations et de replantation.
3. D'évaluer les potentiels d'exploitation de nouvelles ressources sans rompre l'équilibre de cette mangrove (aquaculture en cage, élevage des huitres, développement de l'écotourisme et de la pêche sélective).
4. De mettre en place des mesures favorisant le contrôle des activités d'exploitation (identifier les lacunes de la législation existante et l'adapter au contexte actuel).

En somme, nos résultats révèlent que les activités anthropiques intenses ont conduit à la dégradation et à la déforestation des mangroves camerounaises. Ainsi, dans l'optique de réduire l'émission des gaz à effet de serre, il est dorénavant important d'effectuer un suivi à long terme des impacts des activités anthropiques sur la structure et le fonctionnement de ces forêts intertidales. Ce suivi temporel peut être appliqué dans tous les écosystèmes de mangroves soumis aux fortes pressions anthropiques.

APPENDICES

Abata, T. (1994). *La mangrove de l'estuaire du Wouri (Douala-Cameroun). Etude de la microtopographie et caractérisation morphologique et biochimique des sols*. Mémoire DIPES II, Université de Yaoundé I, Cameroun.

Agho, K., Stevens, G., Taylor, M., Barr, M. & Raphael, B. (2010). Population risk perceptions of global warming in Australia. *Environmental Research*, **110**: 756–763.

Ajonina, G.N. (2008.) *Inventory and monitoring mangrove forest stand dynamics following different levels of wood exploitation pressures in the Douala-Edea Atlantic coast of Cameroon, Central Africa*. Ph.D Thesis, Albert-Ludwigs-Universität Freiburg im Breisgau, Germany.

Aksornkoae, S., Paphavasit, N. & Wattayakorn, G. (1993). *Mangroves of Thailand: present status of conservation, use and management*. In: The economic and environment value of mangrove forests and their present state of conservation. International Tropical Timber Organisation/ Japan International Association for Mangroves/International Society for Mangrove Ecosystems, Japan.

Akum, Z.E. (2005). *Limbe industrial development and pollution*. Available from post online: /http://www.postnewsline.com/2005/07/limbe_industria.html#moreS.

Alemagi, D., Oben, P.M. & Ertel, J. (2006). Mitigating industrial pollution along the atlantic coast of Cameroon: An overview of government efforts. *The Environmentalist*, **26**: 41-50.

Alleman, L.K. & Hester, M.W. (2011). Refinement of the fundamental niche of black mangrove (Avicennia germinans) seedlings in Louisiana: Applications for restoration. *Wetlands Ecology and Management*, **19**: 47-60.

Alongi, D.M. (2002). Present state and future of the world's mangroveforests. *Environmental Conservation*, **29** (3): 331-349.

Alongi, D.M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine Coastal and Shelf Science*, **76**: 1-13.

Alongi, D.M. & De Carvalho, N.A. (2008). The effect of small-scale logging on stand characteristics and soil biogeochemistry in mangrove forests of Timor Leste. *Forest Ecology and management*, **255**: 1359-1366.

Alongi, D.M. (2009). *The energetics of mangrove forests*. Springer publication, UK.

Alongi, D.M. (2011). Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. *Environmental science & policy*, **14**: 462-470.

Ambastha, K.R., Hussain, S.A., Badola, R. & Roy, P.S. (2010). Spatial Analysis of Anthropogenic Disturbances in Mangrove Forests of Bhitarkanika Conservation Area, India. *Journal of the Indian Society of Remote Sensing*, **38**: 67-83.

Anthony, E.J. (2004). Sediment dynamics and morphological stability of estuarine mangrove swamps in Sherbro Bay, West Africa. *Marine Geology*, **208**: 207-224.

Anthony, E.J., Gardel, A., Gratiot, N., Proisy, C., Allison, M.A., Dolique, F. & Fromard, F. (2010). The Amazon-influenced muddy coast of South America: A review of mud-bank-shoreline interactions. *Earth-Science Reviews*, **103**: 99-121.

APG The Angiosperm Phylogeny Group (2009). An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APGIII. *Botanical Journal of the Linnean Society*, **161**: 105-121.

Arulchelvam, K. (1968). Mangroves. *The Ceylon Forester*, **8**: (3 & 4) 59-92.

Aston-Jones, N. (1988). The Human Ecosystem of the Niger Delta: An Era Handbook', Environmental. *Rights Action, Benin-City*, 34-152.

Baba, S., Gordon, C., Kainuma, M., Aviyor, J.S. & Dahdouh-Guebas, F. (2004). *The global mangrove database and information system (GLOMIS): present status and future trends. Proceedings of 'The Colour of Ocean Data' Symposium, Bruxelles, 25-27 Novembre 2002* Edited by: Vanden Berghe E, Brown M, Costello M, Heip C, Levitus S, Pissierssens P. IOC Workshop Reports 188, UNESCO/IOC, Paris.

Baltzer, F., Rudant, J.P. & Tonyé, E. (1995). *Applications de la télédétection micro-onde en bande C (Aéroporté ESAR et satellites ERS1) à la cartographie des mangroves de la région de Douala (Cameroun)*. Proceedings of the second ERS applications workshop, London, UK.

Baltzer, F., Monteillet, J., Din, N., Abata, T., Amougou, A., Kuete, M., Platziat, J.C. & Rudant, J.P. (2001). *Influence of relief and buried architectures on salinity in a deltaic mangrove, Douala Cameroon*. 8ème Congrès Français de Sédimentologie, Livre des résumés, Publ. ASF, Paris, France.

Bandaranayake, W.M. (1998). Traditional and medicinal uses of mangroves. *Mangroves. Salt Marshes*, **2**: 133-148.

Barbier, E.B. & Cox, M. (2003). Does economic development lead to mangrove loss? A cross-country analysis. *Contemporary Economic Policy*, **21** (4): 418-32.

Barbier, E.B. (2003). Habitat-fishery linkages and mangrove loss in Thailand. *Contemporary Economic Policy*, **21** (1): 59-77.

Barbier, E.B. (2007). Valuing ecosystem services as productive inputs. *Economic Policy*, 177-229.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C. & Silliman, B.R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, **81**: 169-193.

Barbier, N., Couteron, P., Lejoly, J., Deblauwe, V. & Lejeune, O. (2006). Self-organized vegetation patterning as a fingerprint of climate and human impact on semi-arid ecosystems. *Journal of Ecology*, **94**: 537-547.

Barbier, N., Couteron, P., Proisy, C., Malhi, Y. & Gastellu-Etchegorry, J.P. (2010). The variation of apparent crown size and canopy heterogeneity across lowland Amazonian forests. *Global Ecology and Biogeography*, **19**: 72-84.

Barbier, N., Proisy C., Véga, C., Sabatier, D. & Couteron, P. (2011). Bidirectional texture function of high resolution optical images of tropical forest: An approach using LiDAR hillshade simulations. *Remote Sensing of Environment*, **115**: 167-179.

Barrett, E. & Curtis, C. (1982). *Introduction to environmental remote sensing*, Chapman and Hall, London, UK.

Berger, U. & Hildenbrandt, H. (2000). A new approach to spatially explicit modelling of forest dynamics: spacing, ageing and neighbourhood competition of mangrove trees. *Ecological Modelling*, **132**: 287-302.

Berger, U., Adams, M., Grimm, V. & Hildenbrandt, H. (2006). Modelling secondary succession of neotropical mangroves: Causes and consequences of growth reduction in pioneer species. *Perspectives in Plant Ecology, Evolution and Systematics*, **7**: 243-252.

Berger, U., Rivera-Monroy, V.H., Doyle, T.W., Dahdouh-Guebas, F., Duke, N., Fontalvo, M., Hildenbrandt, H., Koedam, N., Mehlig, U., Piou, C. & Twilley, R.R. (2008). Advances and limitations of individual-based models to analyze and predict dynamics of mangrove forests: a review. *Aquatic Botany*, **89** (2): 260-274.

Bertrand, F. (1999). Mangrove dynamics in the Rivières du Sud area, West Africa: an ecogeographic approach. *Hydrobiologia*, **413**: 115-126.

Besag, J. (1977). Contribution to the discussion of Dr. Ripley's paper. *J. R. Stat. Soc. B.*, **39**: 193-195.

Besag, J. & Diggle, P.J. (1977). Simple Monte Carlo tests for spatial pattern. *Applied Statistics*, **26** (3): 327-333.

Blanco, J.F., Bejarano, A.C., Lasso, J. & Cantera, J.R. (2001). A new look at computation of the complexity index in mangroves: do disturbed forests have clues to analyze canopy height patchiness? *Wetlands Ecology and Management*, **9**: 91-101.

Bonn, F. (1994). *Télédétection de l'environnement dans l'espace francophone*. Presses de l'Université du Québec, Canada.

Boonsong, K., Plyatiratitivorakul, S. & Patanapompalboon, P. (2003). Potential use of mangrove plantation as constructed wetland for municipal wastewater treatment. *Water Science and Technology*, **48** (5): 257-266.

Bosire, J., Dahdouh-Guebas, F., Kairo, J.G. & Koedam, N. (2003). Colonisation of non-planted mangrove species into restored mangrove stands in Gazi Bay, Kenya. *Aquatic Botany*, **76**: 267-279.

Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Cannicci, S. & Koedam, N. (2004). Spatial variations in macrobenthic fauna recolonisation in a tropical mangrove bay. *Biodiversity and Conservation*, **13**: 1059-1074.

Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Kazungu, J., Dehairs, F. & Koedam, N. (2005a). Litter degradation and CN dynamics in reforested mangrove plantations at Gazi Bay, Kenya. *Biological Conservation*, **126**: 287-296.

Bosire, J.O., Kazungu, J., Koedam, N. & Dahdouh-Guebas, F. (2005b). Predation on propagules regulates regeneration in a high-density reforested mangrove plantation. *Marine Ecology Progress Series*, **299**: 149-155.

Bosire, J.O., Dahdouh-Guebas, F., Kairo, J.G., Wartel, S., Kazungu, J. & Koedam, N. (2006). Success rates and recruited tree species and their contribution to the structural development of reforested mangrove stands. *Marine Ecology Progress Series*, **325**: 85-91.

Bosire, J.O., Dahdouh-Guebas, F., Walton, M., Crona, B.I., Lewis, R.R. III., Field, C., Kairo, J.G. & Koedam, N. (2008). Functionality of restored mangroves: a review. *Aquatic Botany*, **89** (2): 251-259.

Bouillon, S., Dahdouh-Guebas, F., Rao, A.V.V.S., Koedam, N. & Dehairs, F. (2003). Sources of organic carbon in mangrove sediments: variability and possible ecological implications. *Hydrobiologia*, **495**: 33-39.

Bouillon, S., Moens, T., Koedam, N., Dahdouh-Guebas, F., Baeyens, W. & Dehairs, F. (2004). Variability in the origin of carbon substrates for bacterial communities in mangrove sediments. *FEMS, Microbiology Ecology*, **49**: 171-179.

Briggs, S.V. (1977). Estimates of biomass in a temperate mangrove community. *J. Aust. Ecol.*, **2**: 369-373.

Brokaw, N. & Thompson, J. (2000). The H for DBH. *Forest Ecology and Management*, **129**: 89-91.

Cameroon National Institute of Statistics (2009). *Results of the third population census*. Yaoundé, Cameroon.

Cannicci, S., Burrows, D., Fratini, S., Lee, S.Y., Smith, T.J. III, Offenberg, J. & Dahdouh-Guebas, F. (2008). Faunistic impact on vegetation structure and ecosystem function in mangrove forests: a review. *Aquatic Botany*, **89** (2): 186-200.

Cardona-Olarte, P., Twilley, R.R., Krauss, K.W. & Rivera-Monroy, V. (2006). Responses of neotropical mangrove seedlings grown in monoculture and mixed culture under treatments of hydroperiod and salinity. *Hydrobiologia*, **569**: 325-341.

Castaneda-Moya, E., Rivera-Monroy, V.H. & Twilley, R.R. (2006). Mangrove Zonation in the Dry Life Zone of the Gulf of Fonseca, Honduras. *Estuaries and Coasts*, **29**: 751-764.

Ceron-Souza, I., Toro-Perea, N. & Cardenas-Henao, H. (2005). Population Genetic Structure of Neotropical Mangrove Species on the Colombian Pacific Coast: *Avicennia germinans* (Acanthaceae). *Biotropica*, **37**: 258-265.

Chape, S., Harrison, J., Spalding, M. & Lysenko, I. (2005). Measuring the extent and effectiveness of protected areas as an indicator for meeting global biodiversity targets.

Philosophical Transactions of the Royal Society B: Biological Sciences, **360** (1454): 443-455.

Chapman, V.J. (1976). *Mangrove vegetation*. Vaduz: Strauss and Cramer.

Chase, M.W. & Reveal, J.L. (2009). A phylogenetic classification of the land plants to accompany APGIII. *Botanical Journal of the Linnean Society*, **161**: 122-127.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B. & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, **145**: 87-99.

Chen, R. & Twilley, R.R. (1998). A gap dynamic model of mangrove forest development along gradients of soil salinity and nutrient resources. *Journal of Ecology*, **86**: 37-51.

Chimner, R.A., Fry, B., Kaneshiro, M.Y. & Cormier, N. (2006). Current Extent and Historical Expansion of Introduced Mangroves on O‘ahu, Hawai‘i. *Pacific Science*, **60** (3): 377-383.

Cintrón, G. & Schaeffer-Novelli, Y. (1983). *Introducción a la ecología del manglar*. ROSTLAC-UNESCO. Montevideo, Uruguay.

Cintrón, G. & Schaeffer-Novelli, Y. (1984). *Methods for studying mangrove structure*. In: S. C. Snedaker and J. G. Snedaker, eds., The Mangrove Ecosystem: Research Methods. UNESCO, Paris.

Clarke, K.R. & Gorley, R.N. (2001). *PRIMER v6: user manual/tutorial*. PRIMER-E Ltd, Plymouth, UK.

Clarke, P.J. (1993). Dispersal of grey mangrove next term (*Avicennia marina*) propagules in southeastern Australia. *Aquatic Botany*, **45**: 195-204.

Cohen, J.E., Small, C., Mellinger, A., Gallup, J. & Sachs, J. (1997). Estimates of coastal populations. *Science*, **278**: 1209-1213.

Cohen, W.B., Spies, T.A., Alig, R.J., Oetter, D.R., Maiersperger, T.K. & Fiorella, M. (2002). Characterizing 23 years (1972-1995) of stand replacement disturbance in western Oregon forests with Landsat imagery. *Ecosystems*, **5** (2): 122-137.

Cohen, M.C.L., Lara, R.J., Szlafsztein, C. & Dittmar, T. (2004). Mangrove inundation and nutrient dynamics from a GIS perspective. *Wetlands Ecology and Management*, **12**: 81-86.

Conchedda, G., Lambin, E.F. & Mayaux, P. (2011). Between Land and Sea: Livelihoods and Environmental Changes in Mangrove Ecosystems of Senegal', Annals of the Association of American Geographers. *Annals of the Association of American Geographers*, doi: 10.1080/00045608.2011.579534.

Cormier-Salem, M.C. (1994). *Dynamique et usage de la mangrove dans les pays des rivières du sud* (*Du Sénégal à la Sierra Leone*). ORSTOM, Paris, France.

Cormier-Salem, M.C. (1999). *Rivières du Sud: Sociétés et mangroves Ouest-africaines*. Volume 1, IRD, Paris, France.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B. Limburg, K., Naeem S., O'Neill R.V., Paruelo, J., Raskin R.G., Sutton, P. & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, **387**: 253-260.

Cottam, G. & Curtis, J.T. (1956). The use of distance measures in phytosociological sampling. *Ecology*, **37**: 451-460

Couteron, P. (2002). Quantifying change in patterned semi-arid vegetation by Fourier analysis of digitized aerial photographs. *International Journal of Remote Sensing*, **23**: 3407-3425.

Couteron, P., Pélissier, R., Nicolini, E. & Paget, D. (2005). Predicting tropical forest stand structure parameters from Fourier transform of very high-resolution remotely sensed canopy figures. *Journal of Applied Ecology*, **42**: 1121-1128.

Couteron, P., Barbier, N. & Gautier, D. (2006). Textural ordination based on Fourier spectral decomposition: A method to analyze and compare landscape patterns. *Landscape Ecology*, **21**: 555-567.

Crona, B.I., Rönnbäck, P., Jiddawi, N., Ochiewo, J., Maghimbi, S. & Bandeira, S. (2009). Murky water: Analyzing risk perception and stakeholder vulnerability related to sewage impacts in mangroves of East Africa. *Global Environmental Change*, **19**: 227-239.

Cunha-Lignon, M., Mahiques, M.M., Schaeffer-Novelli, Y., Rodrigues, M., Klein, D.A., Goya, S.C., Menghini, R.P., Tolentino, C.V., Cintrón-Molero, G. & Dahdouh-Guebas, F. (2009a). Analysis of mangrove forest succession, using cores: a case study in the Cananéia-Iguape Coastal System, São Paulo – Brazil. *Brazilian Journal of Oceanography*, **57** (3): 161-174.

Cunha-Lignon, M., Coelho-Jr., C., Almeida, R., Menghini, R., Correa, F., Schaeffer-Novelli, Y., Cintrón-Molero, G. & Dahdouh-Guebas, F. (2009b). Mangrove forests and sedimentary processes on the south coast of São Paulo State (Brazil). *Journal of Coastal Research*, **56**: 405-409.

Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G. & Koedam, N. (2000a). Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany*, **54** (4): 513-527.

Dahdouh-Guebas, F., Verheyden, A., De Genst, W., Hettiarachchi, S. & Koedam, N. (2000b). Four decade vegetation dynamics in Sri Lankan mangroves as detected from sequential aerial photography: a case study in Galle. *Bulletin of Marine Science*, **67** (2): 741-759.

Dahdouh-Guebas, F. (2002). The use of Remote Sensing and GIS in the sustainable management of tropical coastal ecosystems. *Environment, Development and Sustainability*, **4**: 93-112.

Dahdouh-Guebas, F. & Koedam, N. (2002). A synthesis of existent and potential mangrove vegetation structure dynamics from Kenyan, Sri Lankan and Mauritanian case-studies.

Meded. Zitt. K. Acad. overzeese Wet./Bull. Séanc. Acad. r. Sci. Outre-Mer, **48** (4): 487-511.

Dahdouh-Guebas, F., Kairo, J.G., Jayatissa, L.P., Cannicci, S. & Koedam, N. (2002). An ordination study to view vegetation structure dynamics in disturbed and undisturbed mangrove forests in Kenya and Sri Lanka. *Plant Ecology*, **161**: 123-135.

Dahdouh-Guebas, F., Van Pottelbergh, I., Kairo, J.G., Cannicci S. & Koedam, N. (2004a). Human-impacted mangroves in Gazi (Kenya): predicting future vegetation based on retrospective remote sensing, social surveys, and distribution of trees. *Marine Ecology Progress Series*, **272**: 77-92.

Dahdouh-Guebas, F., De Bondt, R., Abeysinghe, P.D., Kairo, J.G., Cannicci, S., Triest, L. & Koedam, N. (2004b). Ecologic-comparative study of the disjunct zonation pattern of the grey mangrove *Avicennia marina* (Forsk.) Vierh. in Gazi Bay (Kenya). *Bulletin of Marine Science*, **74** (2): 237-252.

Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D. & Koedam, N. (2005a). How effective were mangroves as a defence against the recent tsunami? *Current Biology*, **15** (12): R443-447.

Dahdouh-Guebas, F., Hettiarachchi, S., Lo Seen, D., Batelaan, O., Sooriyarachchi, S., Jayatissa, L.P. & Koedam, N. (2005b). Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. *Current Biology*, **15**: 579-586.

Dahdouh-Guebas, F., Collin, S., Seen, L.D., Rönnbäck, P., Depommier, D., Ravishankar, T. & Koedam, N. (2006). Analysing ethnobotanical and fishery-related importance of mangroves of the East-Godavari Delta (Andhra Pradesh, India) for conservation and management purposes. *Journal of Ethnobiology and Ethnomedicine*, **2**: 1-24.

Dahdouh-Guebas, F. (2006). *Mangrove forests and tsunami protection*. In : 2006 McGraw-Hill Yearbook of Science & Technology, McGraw-Hill Professional, New York, USA.

Dahdouh-Guebas, F. & Koedam, N. (2006a). Coastal vegetation and the Asian tsunami. *Science*, **311**: 37.

Dahdouh-Guebas, F. & Koedam, N. (2006b). Empirical estimate of the reliability of the use of Point-Centred Quarter Method (PCQM): solution to ambiguous field situation and description of the PCQM+ protocol. *Forest Ecology and Management*, **228**: 1-18.

Dahdouh-Guebas, F., Kairo, J.G., De Bondt, R. & Koedam, N. (2007). Pneumatophore height and density in relation to microtopography in the grey mangrove *Avicennia marina*. *Belgian Journal of Botany*, **140**: 213-221.

Dahdouh-Guebas, F. & Koedam, N. (2008). Long-term retrospection on mangrove development using transdisciplinary approaches: A review. *Aquatic Botany*, **89**: 80-92.

Dahdouh-Guebas, F. (2011). World Atlas of Mangroves: Mark Spalding, Mami Kainuma and Lorna Collins (eds). *Human Ecology*, **39**: 107-109.

Das, S. & Vincent, J.R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. *Proceedings of the National Academy of Sciences of the United States of America*, **106**: 7357-7360.

Datta, D., Guha, P. & Chattopadhyay, R.N. (2010). Application of criteria and indicators in community based sustainable mangrove management in the Sunderbans. *India. Ocean & Coastal Management*, **53**: 468-477.

DeFries, R., Achard, F., Brown, S., Herold, M., Murdiyarso, D., Schlamadinger, B. & de Souza, C. (2007). Earth observations for estimating greenhouse gas emissions from deforestation in developing countries. *Environmental science & policy*, **10**: 385-394.

De Wasseige, C. & Defourny, P. (2002). Retrieval of tropical forest structure characteristics from bi-directional reflectance of SPOT images. *Remote Sensing of Environment*, **83**: 362-375.

Diggle, P.J. (1983). Statistical Analysis of Spatial Point Patterns. New York: Academic Press.

Di Nitto, D., Dahdouh-Guebas, F., Kairo, J.G., Decleir, H. & Koedam, N. (2008). Digital terrain modelling to investigate the effects of sea level rise on mangrove propagule establishment. *Marine Ecology Progress Series*, **356**: 175-188.

Di Nitto, D. (2010). *To go with the flow. A field and modeling approach of hydrochorous mangrove propagule dispersal*. PhD dissertation, Vrije Universiteit Brussel-Université Libre de Bruxelles, 1050 Brussels, Belgium.

Din, N. (1993). *Contribution à l'étude botanique et écologique des mangroves de l'estuaire du Cameroun*. Thèse de Doctorat du 3eme Cycle, Université de Yaoundé, Cameroon.

Din, N. & Blasco, F. (1998). Mangroves du Cameroun, statut écologique et déforestation. In *Géosciences au Cameroun* Edited by: Vicat J.P., Bilong P. Presses Univ. Cameroun.

Din, N.-2001. *Mangrove du Cameroun: statut écologique et perspectives de gestion durable*. Thèse d'Etat, Université de Yaoundé I, Cameroun.

Din, N., Lacaze, D. & Blasco, F. (2001a). *Carte thématique des mangroves de l'estuaire du Rio del Rey (Cameroun) par photo-interprétation et SIG*. 4^{e} symposium international sur la cartographie informatisée et les SIG destinées à la gestion des zones côtières. 18-20 juin 2001, Halifax, Canada.

Din, N., Priso, R.J., Dibong, S.D. & Amougou, A. (2001b). Identification des principales causes de dégradation des mangroves dans l'estuaire du Cameroun. *Sci. Technol. Dev.*, **8** (1): 1-7.

Din, N., Priso, R.J., Kenne, M., Ngollo, D.E. & Blasco, F. (2002a). Early growth stages and natural regeneration of *Avicennia germinans* (L.) Stearn in the Wouri estuarine mangroves (Douala-Cameroon). *Wetlands Ecology and Management*, **10**: 461-472.

Din, N., Tientcheu, Y.J., Ayamama, A.C., Ngollo, D.E. & Blasco, F. (2002b). Possible impact of climate change on the mangrove forest ecosystem of the Cameroon estuary. *Sci. Technol. Dev.*, **9** (1): 21-27.

Din, N. & Ngollo, D.E. (2002). Perspectives for Sustainable Management of Mangrove Ecosystems in Cameroon. *European Tropical Forest Research Network NEWS*, **36** (2): 48-51.

Din, N., Saenger, P., Priso, R.J., Dibong, D.S. & Blasco, F. (2008). Logging activities in mangrove forests: A case study of Douala Cameroon. *African Journal of Environmental Science and Technology*, **2** (2): 22-30.

Diop, E.S., ed. (1993). *Conservation and sustainable utilization of mangrove forests in Latin America and African regions (part 2: Africa)*. Mangrove Ecosystem Technical Reports 3, International Society for Mangrove Ecosystems and International Tropical Timber Organization Tokyo.

D'Iorio, M., Jupiter, S.D., Cochran, S.A. & Potts, D.C. (2007). Optimizing Remote Sensing and GIS Tools for Mapping and Managing the Distribution of an Invasive Mangrove (*Rhizophora mangle*) on South Molokai, Hawaii. *Marine Geodesy*, **30**: 125-144.

Dobson, A.P., Bradshaw, A.D. & Baker, A.J.M. (1997). Hopes for the future: restoration ecology and conservation biology. *Science*, **277**: 515-522.

Dodd, R.S., Rafiik, Z.A., Fromard, F. & Blasco, F. (1998). Evolutionary diversity among Atlantic coast mangroves. *Acta Oecologica*, **19** (3): 323-330.

Dodd, R.S., Raf II, Z.A. & Bousquet-Mélou, (2000). Evolutionary divergence in the pan-Atlantic mangrove *Avicennia germinans*. *New Phytologist*, **145**: 115-125.

Donato, D.C., Boone Kauffman, J., Murdiyarso, D., Kurnianto, S., Stidham, M. & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature geosciences (Letters)*, **4**: 293-297.

Doust, H. & Omatsola, E. (1990). *Niger Delta*. In: Edwards, J.D., Santogrossi, P.A. (Eds.), Divergent/Passive Margin Basins, AAPG Memoir 48. American Association of Petroleum Geologists, Tulsa, pp. 239-248.

Duke, N.C. (1992). *Coastal and Estuarine studies: Tropical Mangrove Ecosystems*. In: Robertson, A.I. and Alongi, D.M. (Eds.). American Geophysical Union, Washington DC., USA.

Duke, N.C., Pinzon, Z.S.M. & Prada, M.C.T. (1997). Large-scale damage to mangrove forests following two large oil spills in Panama. *Biotropica*, **29** (1): 2-14.

Duke, N.C. & Schwarzbach, A.E. (2001). Life on the edge: Past and future of mangroves. *Wetlands Ecology and Management*, **9**: 159.

Duke, N.C. (2006). *Australia's Mangroves: the Authoritative Guide to Australia's Mangrove Plants*. St Lucia, Australia: University of Queensland.

Duke, N.C., Meynecke, J.O., Dittmann, S., Ellison, A.M., Anger, K., Berger, U., Cannicci, S., Diele, K., Ewel, K.C., Field, C.D., Koedam, N., Lee, S.Y., Marchand, C., Nordhaus, I. & Dahdouh-Guebas, F. (2007). A world without mangroves? *Science*, **317**: 41-42.

Ehrlich, P.R. & Mooney, H.A. (1983). Extinction, substitution, and ecosystem services. *BioScience*, **33**: 248-254.

Ellison, A.M., Farnsworth, E.J. & Mertkt, R.E. (1999). Origins of mangrove ecosystems and the mangrove biodiversity anomaly. *Global Ecology and Biogeography*, **8**: 95-115.

Ellison, J.C. (2003). How South Pacific mangroves may respond to predicted climate change and sea-level rise. *Advances in Global Change Research*, **2**: 289-300.

Ellison, A.M. (2008). Managing mangroves with benthic biodiversity in mind: moving beyond roving banditry. *Journal of Sea Research*, **59**: 2-15.

Elzinga, C.L., Salzer, D.W., Willoughby, J.W. & Gibbs, J.P. (2001). *Monitoring Plant and Animal Populations*. Blackwell Science, Inc., Malden, Massachusetts, USA.

Eong, O.J. (1993). Mangroves_a carbon source and sink. *Chemosphere*, **27**: 1097-1107.

Eslami-Andargoli, L., Per Dale, Sipe, N. & Chaseling, J. (2009). Mangrove expansion and rainfall patterns in Moreton Bay, Southeast Queensland, Australia. *Estuarine, Coastal and Shelf Science*, **85**: 292-298.

Everitt, J.H., Yang, C., Summy, K.R., Judd, F.W. & Davis, M.R. (2007). Evaluation of Color-Infrared Photography and Digital Imagery to Map Black Mangrove on the Texas Gulf Coast. *Journal of Coastal Research*, **23** (1): 230-235.

Everitt, J.H., Yang, C., Sriharan, S. & Judd, F.W. (2008). Using High Resolution Satellite Imagery to Map Black Mangrove on the Texas Gulf Coast. *Journal of Coastal Research*, **24** (6): 1582-1586.

Everitt, J.H., Yang, C., Judd, F.W. & Summy, K.R. (2010). Use of Archive Aerial Photography for Monitoring Black Mangrove Populations. *Journal of Coastal Research*, **26** (4): 649-653.

Ewel, K.C., Twilley, R.R. & Ong, J.E. (1998). Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography*, **7**: 83-94.

FAO (1985). *Mangrove management in Thailand, Malaysia and Indonesia*. Food and Agriculture Organization of the United Nations Environment Paper 4 Rome.

FAO (1994). *Mangrove forest management guidelines*. Food and Agriculture Organisation of the United Nations Forestry paper Rome.

FAO (2007). *The world's mangroves* 1980-2005. Food and Agriculture Organisation of the United Nations Forestry paper Rome.

Farley, J., Erickson, J. & Daly, H. (2005). *Ecological economics: a workbook in problem based learning*. Island Press, Washington DC, USA.

Farley, J., Batker, D., de la Torre, I. & Hudspeth, T. (2010). Conserving Mangrove Ecosystems in the Philippines: Transcending Disciplinary and Institutional Borders. *Environmental Management*, **45**: 39-51.

Farnsworth, E.J. & Ellison, A.M. (1997). The global conservation status of mangroves. *Ambio*, **26** (6): 328-334.

Farnsworth, E.J. (2004). Forging research partnerships across the academic-agency divide. *Conservation Biology*, **18** (2): 291-293.

Fatoyinbo, T.E, Simard, M., Washington-Allen, R.A. & Shugart, H.H. (2008). Landscape-scale extent, height, biomass, and carbon estimation of Mozambique's mangrove forests with Landsat ETM+ and Shuttle Radar Topography Mission elevation data. *Journal of Geophysical Research*, **113**, G02S06, pp 13.

Feagin, R., Mukherjee, N., Shanker, K., Baird, A.H., Cinner, J., Kerr, A.M., Koedam, N., Sridhar, A., Arthur, R., Jayatissa, L.P., Seen, D.L., Menon, M., Rodriguez, S., Shamsuddoha, M. & Dahdouh-Guebas, F. (2010). Shelter from the storm? The use and misuse of ‘‘bioshields’’ in managing for natural disasters on the coast. *Conservation Letters*, **3** (1): 1-11.

Feka, N.Z. (2005). *Perspectives for the sustainable management of mangrove stands in the Douala-Edea wildlife reserve*, *Cameroon*. Master thesis, University of Buea, Cameroon.

Feka, N.Z. & Manzano, M.J. (2008). The implications of wood exploitation for fish smoking on mangrove ecosystem conservation in the South West Province, Cameroon. *Tropical Conservation Science*, **1**: 222-235.

Feka, N.Z., Chuyong, G.B. & Ajonina, G.N. (2009). Sustainable utilization of mangroves using improved fish-smoking systems: a management perspective from the Douala-Edea wildlife reserve, Cameroon. *Tropical Conservation Science*, **4** (2): 450-468.

Feller, I.C., Lovelock, C.E. & McKee, K.L. (2007). Nutrient Addition Differentially Affects Ecological Processes of *Avicennia germinans* in Nitrogen versus Phosphorus Limited Mangrove Ecosystems. *Ecosystems*, **10**: 347-359.

Field, C.D. (1999). Mangrove rehabilitation: choice and necessity. *Hydrobiology*, **413**: 47-52.

Fromard, F., Puig, H., Mougin, E., Marty, G., Betoulle, J.L. & Cadamuro, L. (1998). Structure, above-ground biomass and dynamics of mangrove ecosystems: New data from French Guiana. *Oecologia*, **115**: 39-53.

Fromard, F., Vega, C. & Proisy, C. (2004). Half a century of dynamic coastal change affecting mangrove shorelines of French Guiana. A case study based on remote sensing data analyses and field surveys. *Marine Geology*, **208**: 265-280.

Glaser, M. (2003). Interrelations between mangrove ecosystem, local economy and social sustainability in Caete Estuary, North Brazil. *Wetlands Ecology and Management*, **11**: 265-272.

Gilman, E., Van Lavieren, H., Ellison, J., Jungblut, V., Wilson, L., Areki, F., Brighouse, G., Bungitak, J., Dus, E., Henry, M., Kilman, M., Matthews, E., Sauni, J.I., Teariki-Ruatu, N., Tukia, S. & Yuknavage, K. (2006). *Pacific Island Mangroves in a Changing Climate and Rising Sea*. UNEP Regional Seas Reports and Studies No. 179. United Nations Environment Programme, Regional Seas Programme, Nairobi, Kenya.

Gilman, E.L., Ellison, J., Duke, N.C. & Field, C. (2008). Threats to mangroves from climate change and adaptation options: A review. *Aquatic Botany*, **89**: 237-250.

Giresse, P., Megope-Foonde, J.P., Ngueutchoua, G., Aloisi, J.C., Kuete, M., Monteillet, J. (1996). *Carte sédimentologique du plateau continental du Cameroun à* 1: 200000. ORSTOM, Paris, France.

Giresse, P. & Maley, J. (1998). The dynamic of organic carbon in South Cameroon: fluxes in a tropical river system and a lack system as a varying sink on a glacial-interglacial time scale. *Global and Planetary Change*, 16-17: 53-74.

Giri, C., Pengra, B., Zhu, Z., Singh, A. & Tieszen, L.L. (2007). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. *Estuarine, Coastal and Shelf Science*, **73**: 91-100.

Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J. & Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, **20** (1): 154-159.

Goreaud, F. & Pélissier, R. (1999). On explicit formulas of edge effect correction for Ripley's K-function. *Journal of Vegetation Science*, **10**: 433-438.

Granek, E. & Ruttenberg, B.I. (2008) Changes in biotic and abiotic processes following mangrove clearing. *Estuarine, Coastal and Shelf Science*, **80**: 555-562.

Guimarães, A.S., Travassos, P., Filho, P.W.M.E.S., Gonçalves, F.D. & Costa, F. (2010). Impact of aquaculture on mangrove areas in the northern Pernambuco Coast (Brazil) using remote sensing and geographic information system. *Aquaculture Research*, **41**: 828-838.

Hauff, R.D., Ewel, K.C. & Jack, J. (2006). Tracking human disturbance in mangroves: Estimating harvest rates on a Micronesian island. *Wetlands Ecology and Management*, **14**: 95-105.

Hedin, L. (1928). L'exploitation du palétuvier dans la baie de Manoka (Cameroun). *Rev. Bot. Appl. Agr. Col.*, **8**: 623-626.

Hernández-Cornejo, R., Koedam, N., Ruiz Luna, A., Troell, M. & Dahdouh-Guebas, F. (2005). Remote Sensing and Ethnobotanical Assessment of the Mangrove Forest Changes in the Navachiste-San Ignacio-Macapule Lagoon Complex, Sinaloa, Mexico. *Ecology and Society*, **10** (1): 16.

Hester, M.W., Henkel, T.K., Willis, J.M. & Taylor, P.A. (2007). *Enhancement of barrier island marsh creation through black mangrove propagule dispersal: A cost-effective alternative to planting seedlings*. Final Report, NOAA/CREST (Coastal Restoration Enhancement through Science and Technology).

Heumann, B.W. (2011). Satellite remote sensing of mangrove forests: Recent advances and future opportunities. *Progress in Physical Geography*, **35** (1): 87-108.

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liang, T. & Tosi, J.A. (1971). *Forest environment in tropical life zones*. Pergamon Press, New York, USA.

Hong, P.N. & San, H.T. (1993). *Mangrove of Vietnam*. IUCN, Gland Switzerland.

Hossain, M.Z., Tripathi, N.K. & Gallardo, W.G. (2009). Land Use Dynamics in a Marine Protected Area System in Lower Andaman Coast of Thailand, 1990-2005. *Journal of Coastal Research*, **25** (5): 1082-1095.

Houghton, R.A. (1994). The worldwide extent of land-use change. *BioScience*, **44**: 305-313.

Howland, W.G. (1980). Multispectral aerial photography for wetland vegetation mapping. *Photogrammetric Engineering and Remote Sensing*, **46**: 87-99.

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X. & Ferreira, L.G. (2002). Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote sensing of Environment*, **83**: 195-213.

Inoue, T., Nohara, S., Takagi, H. & Anzai, Y. (2011). Contrast of nitrogen contents around roots of mangrove plants. *Plant Soil*, **339**: 471-483.

IPCC (2006). *Guidelines for National Greenhouse Gas Inventories*. Volume 4 Agriculture, Forestry and Other Land Use (GL-AFOLU). Available online at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4. html.

Jayatissa, L.P., Dahdouh-Guebas, F. & Koedam, N. (2002). A review of the floral composition and distribution of mangroves in Sri Lanka. *Botanical Journal of the Linnean Society*, **138**: 29-43.

Jayaraman, K. (2000). *A statistical manual for forestry research*. FORSPA-FAO, Bangkok, Thailand.

Kairo, J.G., Dahdouh-Guebas, F., Gwada, P.O., Ochieng, C. & Koedam, N. (2002). Regeneration status of mangrove forests in Mida creek: a compromised or secured future? *Ambio*, **31**: 7-8.

Kaly, U.L., Eugelink, G. & Robertson, A. (1997). Soil conditions in damaged North Queensland mangroves. *Estuaries*, **20** (2): 291-300.

Kathiresan, K. & Bingham, B.L. (2001). Biology of Mangroves and Mangrove Ecosystems. *Advances in marine biology*, **40**: 81-251.

Kauffman J.B., Heider, C., Cole, T.G., Dwire, K.A. & Donato, D.C. (2011). Ecosystem Carbon Stocks of Micronesian Mangrove Forests. *Wetlands*, **31**: 343-352.

Kent, M. & Coker, P. (1992). *Vegetation Description and Analysis. A practical Approach*. John Wiley & Sons, Chichester, UK.

Kerr, A.M. & Baird, A.H. (2007). Natural barriers to natural disasters. *Bioscience*, **57**: 102-103.

Khan, M.N.I., Suwa, R. & Hagihara, A. (2007). Carbon and nitrogen pools in a mangrove stand of Kandelia obovata (S., L.) Yong: vertical distribution in the soil–vegetation system. *Wetlands Ecology and Management*, **15**: 141-153.

Kint, V., Robert, D.W. & Noel, L. (2004). Evaluation of sampling methods for the estimation of structural indices in forest stands. *Ecological Modelling*, **180**: 461-476.

Klintenberg, P. & Seely, M. (2004). Land degradation monitoring in Namibia: A first approximation. *Environmental Monitoring and Assessment*, **99**: 5-21.

Klintenberg, P., Seely, M. & Christiansson, C. (2007). Local and national perceptions of environmental change in central Northern Namibia: Do they correspond? *Journal of Arid Environments*, **69**: 506-525.

Koch, M.S. & Snedaker, S.C. (1997). Factors influencing *Rhizophora mangle* L. seedling development in Everglades carbonate soils. *Aquatic Botany*, **59**: 87-98.

Koedam, N. & Dahdouh-Guebas, F. (2008). Ecological quality changes precede changes in quality in mangrove forests. *Science*, (E-letter 02/10/2008).

Komiyama, A., Havanond, S., Srisawatt, W., Mochida, Y., Fujimoto, K., Ohnishi, T., Ishihara, S. & Miyagi, T. (2000). Top/root biomass ratio of a secondary mangrove (*Ceriops tagal* (Perr.) C.B. Rob.) forest. *Forest Ecology and Management*, **139**: 127-134.

Komiyama, A., Poungparn, S. & Kato, S. (2005). Common allometric equations for estimating the tree weight of mangroves. *Journal of Tropical Ecology*, **21**: 471-477.

Komiyama, A., Ong, J.E. & Poungparn, S. (2008). Allometry, biomass and productivity of mangrove forests: a review. *Aquatic Botany*, **89** (2): 128-137.

Kovacs, J.M. (1999). Assessing mangrove use at the local scale. *Landscape and Urban Planning*, **43** (4): 201-208.

Kovacs, J.M. (2000). Perceptions of environmental change in a tropical coastal wetland. *Land Degradation and. Development*, **11**: 209-220.

Kovacs, J.M., Malczewskit, J. & Flores-Verdugo, F. (2004). Examining local ecological knowledge of hurricane impacts in a mangrove forest using an Analytical Hierarchy Process (AHP) Approach. *Journal of Coastal Research*, **20** (3): 792-800.

Kovacs, J.M., Wang, J. & Flores-Verdugo, F. (2005). Mapping mangrove leaf area index at the species level using IKONOS and LAI-2000 sensors for the Agua Brava Lagoon, Mexican Pacific. *Estuarine, Coastal and Shelf Science*, **62**: 377-384.

Kovacs, J.M., Flores de Santiago, F., Bastien, J. & Lafrance, P. (2010). An Assessment of Mangroves in Guinea, West Africa, Using a Field and Remote Sensing Based Approach. *Wetlands*, **30**: 773-782.

Krause, G., Bock, M., Weiers, S. & Braun, G. (2004). Mapping Land-Cover and Mangrove Structures with Remote Sensing Techniques: A Contribution to a Synoptic GIS in Support of Coastal Management in North Brazil. *Environmental management*, **34** (3): 429-440.

Krauss, K.W., Lovelock, C.E., McKee, K.L., Lopez-Hoffman, L., Ewe, S.M. & Sousa, W.P. (2008). Environmental drivers in mangrove establishment and early development: a review. *Aquatic Botany*, **89** (2): 105-127.

Kristensen, E., Bouillon, S., Dittmar, T. & Marchand, C. (2008). Organic carbon dynamics in mangrove ecosystems: a review. *Aquatic Botany*, **89** (2): 201-219.

Krumbein, W.C. & Pettijohn, F.J. (1938). *Manual of sedimentary petrography* Appleton century-crafts, New York, USA.

Kumara, M.P., Jayatissa, L.P., Krauss, K.W., Phillips, D.H. & Huxham, M. (2010). High mangrove density enhances surface accretion, surface elevation change, and tree survival in coastal areas susceptible to sea-level rise. *Oecologia*, **164**: 545-553.

Kunstadter, P., Bird, E.C.F. & Sabhasri, S. (eds) (1986). *Man in the Mangroves* United Nations University, Tokyo.

Lacerda, L.D. (ed) (1993). *Conservation and sustainable utilization of mangrove forests in Latin America and African regions (part 1: Latin America)* Mangrove Ecosystem Technical Reports 2, International Society for Mangrove Ecosystems and International Tropical Timber Organization Tokyo.

Lacerda, L.D., Conde, J.E., Kjerfve, B., Alvarez-Leon, R., Alarcon, C. & Polania, J. (2002). *American mangroves*. In: Lacerda L.D. (ed). Mangrove Ecosystems: Function and Management. Berlin, Germany.

Lambshead, P.J.D., Platt, H.M. & Shaw, K.M. (1983). The detection of differences among assemblages of marine benthic species based on an assessment of dominance and diversity. *Journal of natural History*, **17**: 859-874.

Lamparelli, C.C., Rodrigues, F.O. & Orgler de Moura, D. (1997). *Long-term assessment of an oil spill in a mangrove forest in Sao Paulo, Brazil*, In: Kjerfve, B., L.D., Lacerda, de L.D & Diop, E.H.S. (éds.), Mangrove Ecosystem Studies in Latin America and Africa, UNESCO, Paris, France.

Lara, R.J. & Dittmar, T. (1999). Nutrient dynamics in a mangrove creek (North Brazil) during the dry season. *Mangroves and Salt Marshes*, **3**: 185-195.

Lehmann, A. & Lachavanne, J.B. (1997). Geographic information system and remote sensing in aquatic botany. *Aquatic Botany*, **58**: 195-207.

Legendre, P. & Legendre, L. (1998). *Numerical ecology (2nd ed.)*. The Netherlands: Elsevier.

Lieth, H., Berlekamp, J., Fuest, S. & Riediger, S. (1999). *Climate diagram world atlas*. Backhuys, Leiden.

Lewis, III R.R. (2005). Ecological engineering for successful management and restoration of 727 mangrove forests. *Ecological Engineering*, **24**: 403-418.

Li, X., Gar-On Yeh, A., Wang, S., Liu, K., Liu, X., Qian, J. & Chen, X. (2007). Regression and analytical models for estimating mangrove wetland biomass in South China using Radarsat images. *International Journal of Remote Sensing*, **28** (24): 5567-5582.

Lin, B.B. & Dushoff, J. (2004). Mangrove filtration of anthropogenic nutrients in the Rio Coco Solo, Panama. *Management of Environmental Quality: An International Journal*, **15**: 131-142.

Lopez-Hoffman, L., Monroe, I.E., Narvaez, E., Martinez-Ramos, M. & Ackerly, D.D. (2006). Sustainability of mangrove harvesting: How do harvesters' perceptions differ from ecological analysis? *Ecology and Society*, **11** (2): art 14.

Lovelock, C.E., Ruess, R.W. & Feller, I.C. (2011). CO_2 Efflux from Cleared Mangrove Peat. *PLoS ONE*, **6** (6): e21279.

Lu, D., Mausel, P., Brondizio, E. & Moran, E. (2004). Relationships between forest stand parameters and Landsat TM spectral responses in the Brazilian Amazon Basin. *Forest Ecology and Management*, **198**: 149-167.

Ludwig, J.A. & Reynolds, J.F. (1988). *Statistical Ecology, A primer on methods and computing*. New York, USA.

Lugo, A.E. & Snedaker, SC. (1974). The ecology of mangroves. *Annual Review of Ecology and Systematics*, **5**: 39-63.

Luo, Z., Sun, O.J., Wang, E., Ren, H. & Xu, H. (2010). Modeling Productivity in Mangrove Forests as Impacted by Effective Soil Water Availability and Its Sensitivity to Climate Change Using Biome-BGC. *Ecosystems*, **13**: 949-965.

Luo, Z., Sun, O.J. & Xu, H. (2010). A comparison of species composition and stand structure between planted and natural mangrove forests in Shenzhen Bay, South China. *Journal of Plant Ecology*, **3** (3): 165-174.

Macnae, W. (1968). A general account of the fauna and flora of mangrove swamps and forests of the Indo-West-Pacific region. *Advances in Marine Biology*, **6**: 73-270.

Massó i Alemán, S., Bourgeois, C., Appeltans, W., Vanhoorne, B., De Hauwere, N., Stoffelen, P., Heaghebaert, A. & Dahdouh-Guebas, F. (2010). The 'Mangrove Reference Database and Herbarium'. *Plant Ecology and Evolution*, **143** (2): 225-232.

Matthijs, S., Tack, J., Van Speybroeck, D. & Koedam, N. (1999). Mangrove species zonation and soil redox state, sulphide concentration and salinity in Gazi Bay (Kenya), a preliminary study. *Mangroves and Salt Marshes*, **3**: 243-249.

Mazda, Y., Kobashi, D. & Okada, S. (2005). Tidal-scale hydrodynamics within mangrove swamps. *Wetlands Ecology and Management*, **13**: 647-655.

Mbendi (2005). *Oil and gas industry: Exploration and production upstream*. /http://www.mbendi.co.za/indy/oilg/ogus/af/ca/p0005.htm#2S.

McKee, K.L. (1995). Seedling recruitment patterns in a Belizean mangrove forest: effects of establishment ability and physico-chemical factors. *Oecologia*, **101**: 448-460.

McKee, K.L. (2004). Global *Change Impacts on Mangrove Ecosystems*. U.S. Department of the Interior, U.S. Geological Survey. http://earthscape.org/r1/ES16755/USGS_GlobalChange.pdf.

MINEF (1996). *Plan national de gestion de l'environnement. Analyse des secteurs d'intervention.* Volume II, Yaoundé, Cameroun.

MINEP (2004). *Rapport national sur la mise en œuvre de la convention des nations unies sur la lutte contre la désertification*. Yaoundé, Cameroun.

MINEP (2008). *Rapport sur l'état de la biodiversité marine et côtière du Cameroun*. Yaoundé, Cameroun.

Mitchell, B. (1997). *Resource and Environmental Management*. Addison Wesley Longman, Harlow.

Mitchell, K. (2007). *Quantitative analysis by the point-centered quarter method*. Department of Mathematics and Computer Science, Hobart and William Smith Colleges. Available: http://people.hws.edu/Mitchell/PCQM.pdf.

Mitchell, A.L., Lucas, R.M., Donnelly, B.E., Pfitzner, K., Milne, A.K. & Finlayson, M. (2007). A new map of mangroves for Kakadu National Park, Northern Australia, based on stereo aerial photography. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **17**: 446-467.

Mitra, A., Sengupta, K. & Banerjee, K. (2011). Standing biomass and carbon storage of above-ground structures in dominant mangrove trees in the Sundarbans. *Forest Ecology and Management*, **261**: 1325-1335.

Mmom, P.C. & Arokoyu, S.B. (2010). Mangrove Forest Depletion, Biodiversity Loss and Traditional Resources Management Practices in the Niger Delta, Nigeria. *Research Journal of Applied Sciences, Engineering and Technology*, **2** (1): 28-34.

Mohamed, M.O.S., Neukermans, G., Kairo, J.G., Dahdouh-Guebas, F. & Koedam, N. (2009). Mangrove forests in a peri-urban setting: the case of Mombasa (Kenya). *Wetlands Ecology and Management*, **17**: 243-255.

Mougin, E., Proisy, C., Marty, G., Fromard, F., Puig, H., Betoulle, J.L. & Rudant, J.P. (1999). Multifrequency and multipolarization radar backscattering from mangrove forests. *IEEE Transactions on Geoscience and Remote Sensing*, **37**: 94-102.

Mukherjee, N., Dahdouh-Guebas, F., Kapoor, V., Arthur, R., Koedam, N., Sridhar, A. & Shanker, K. (2010). From Bathymetry to Bioshields: A Review of Post-Tsunami Ecological Research in India and its Implications for Policy. *Environmental Management*, **46**: 329-339.

Mumby, P.J., Edwards, A.J., Arlas-González, J.E., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczynska, M.I., Harborne, A.R.., Pescod, C.L., Renken, H., Wabnitz, C.C.C. & Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*, **427**: 533-536.

Myers, E.C.M. (2008) *Policies to reduce emissions from deforestation and degradation in developing countries: An examination of the issues facing the incorporation of REDD into market-based climate policies*. Resource for the future, Washington DC, USA.

Nagelkerken, I., Blaber, S., Bouillon, S., Green, P., Haywood, M., Kirton, L.G., Meynecke, J.O., Pawlik, J., Penrose, H.M., Sasekumar, A. & Somerfield, P.J. (2008). The habitat function of mangroves for terrestrial and marine fauna: a review. *Aquatic Botany*, **89** (2): 155-185.

Nave, L.E., Vance, E.D., Swanston, C.W. & Curtis, P.S. (2010). Harvest impacts on soil carbon storage in temperate forests. *Forest Ecology and Management*, **259**: 857-866.

Ndenecho, E.N. (2007). Economic value and management of mangrove forests in Cameroon. *The International Journal of Sustainable Development and World Ecology*, **14** (6): 618-625.

Nfotabong Atheull, A. (2008). *Utilisation des mangroves par les habitants des zones côtières près de Kribi, du Nyong et de l'estuaire du Cameroun*. Mémoire de DEA, Université Libre de Bruxelles-ULB, Bruxelles, Belgique.

Nfotabong Atheull, A., Din, N., Longonje, S.N., Koedam, N. & Dahdouh-Guebas, F. (2009). Commercial activities and subsistence utilization of mangrove forests around the Wouri estuary and the Douala-Edea reserve (Cameroon). *Journal of Ethnobiology and Ethnomedicine*, **5**: 35.

Neukermans, G., Dahdouh-Guebas, F., Kairo, J.G. & Koedam, N. (2008). Mangrove species and stand mapping in Gazi Bay (Kenya) using Quickbird satellite imagery. *Journal of Spatial Science*, **52** (1): 75-86.

Obade, P.T., Koedam, N., Soetaert, K., Neukermans, G., Bogaert, J., Nyssen, E., Van Nedervelde, F., Berger, U. & Dahdouh-Guebas, F. (2009). Impact of anthropogenic disturbance on a mangrove forest assessed by a 1D Cellular automaton model using Lotka–Volterra-type competition. *International Journal of Design & Nature and Ecodynamics*, **3**: 296-320.

Olivry, J.C. (1986). *Fleuves et rivières du Cameroun*. Monographies Hydrologiques. ORSTOM, Paris.

Osborne, D.J. & Berjak, P. (1997). The making of mangroves : the remarkable pioneering role played by seeds of *Avicennia marina*. *Endeavour*, **21**: 143-147.

Osuji, L.C., Ayolaghab, G., Obutec, G.C. & Ohabuike, H.C. (2007). Chemical and Biogeophysical Impact of Four-Dimensional (4D) Seismic Exploration in Sub-Saharan Africa, and Restoration of Dysfunctionalized Mangrove Forests in the Prospect Areas. *Chemistry & Biodiversity*, **4**: 2149-2165.

Osuji, L.C., Erondub, E.S. & Ogalia, R.E. (2010). Upstream Petroleum Degradation of Mangroves and Intertidal Shores: The Niger Delta Experience. *Chemistry and Biodiversity*, **7**: 116-128.

Patterson, C.S., Mendelssohn, I.A. & Swenson, E.M. (1993). Growth and Survival of *Avicennia germinans* Seedlings in a Mangal/Salt Marsh Community in Louisiana, U.S.A. *Journal of Coastal Research*, **9**: 801-810.

Penha-Lopes, G., Torres, P., Cannicci, S., Narciso, L. & Paula, J. (2011). Monitoring anthropogenic sewage pollution on mangrove creeks in southern Mozambique: A test of Palaemon concinnus Dana, 1852 (Palaemonidae) as a biological indicator. *Environmental Pollution*, **159**: 636-645.

Perry, C.L. & Mendelssohn, I.A. (2009). Ecosystem effects of expanding populations of *Avicennia germinans* in a Louisiana salt marsh. *Wetlands*, **29** (1): 396-406.

Pickens, C.N. & Hester, M.W. (2011). Temperature Tolerance of Early Life History Stages of Black Mangrove *Avicennia germinans*: Implications for Range Expansion. *Estuaries and Coasts*, **34**: 824-830.

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison J.C., Farnsworth, E.J., Fernando, E.S., Kathiresan, K., Koedam, N.E., Livingstone, S.R., Miyagi, T., Moore, G.E., Nam, V.N., Ong, J.E., Primavera, J.H., Salmo, III S.G., Sanciangco, J.C., Sukardjo, S., Wang, Y. & Yong, J.W.H. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE*, **5**: 4.

Pretzsch, H., Biber, P. & Dursky, J. (2002). The single tree-based stand simulator SILVA: construction, application and evaluation. *Forest Ecology and Management*, **162**: 3-21.

Proisy, C., Mougin, E., Fromard, F. & Karam, M.A. (2000). Interpretation of polarimetric radar signatures of Mangrove forests. *Remote Sensing of Environment*, **71**: 56-66.

Proisy, C., Couteron, P. & Fromard, F. (2007). Predicting and mapping mangrove biomass from canopy grain analysis using Fourier-based textural ordination of IKONOS images. *Remote Sensing of Environment*, **109**: 379-392.

Proisy, C., Gratiot, N., Anthony, E.J., Gardel, A., Fromard, F. & Heuret, P. (2009). Mud bank colonization by opportunistic mangroves: A case study from French Guiana using lidar data. *Continental Shelf Research*, **29**: 632-641.

Rabinowitz, D. (1978). Dispersal properties of mangrove propagules. *Biotropica*, **10**: 47-57.

Rajkaran, A., Adams, J. & Taylor, R. (2010). Historic and recent (2006) state of mangroves in small estuaries from Mlalazi to Mtamvuna in KwaZulu-Natal, South Africa. *Southern Forests: a Journal of Forest Science*, **71** (4): 287-296.

Rakotomavo, A. & Fromard, F. (2010). Dynamics of mangrove forests in the Mangoky River delta, Madagascar, under the influence of natural and human factors. *Forest Ecology and Management*, **259**: 1161-1169.

RAMSAR (1994). *Convention relative aux zones humides d'importance internationales particulièrement comme habitats des oiseaux d'eaux*. Office des Normes Internationales et des Affaires Juridiques, UNESCO, Paris.

Rasolofo, M.V. (1997). Use of mangroves by traditional fishermen in Madagascar. *Mangroves and Salt Marshes*, **1**: 243-253.

Ricklefs, R.E. & Latham, R.E. (1993). *Global patterns of diversity in mangrove floras*. In: Ricklefs, R.E., Schluter, D, eds. Species diversity in ecological communities' historical and geographical perspectives. Chicago, University of Chicago Press, USA.

Ripley, B.D. (1977). Modelling spatial patterns. *J. R. Stat. Soc., B.*, **39**: 172-212.

Rist, S. & Dahdouh-Guebas, F. (2006). Ethnosciences - A step towards the integration of scientific and traditional forms of knowledge in the management of natural resources for the future. *Environment, Development and Sustainability*, **8**: 467-493.

Robert, E.M.R., Schmitz, N., Boeren, I., Driessens, T., Herremans, K., De Mey, J., Van de Casteele, E., Beeckman, H. & Koedam, N. (2011). Successive Cambia: A Developmental Oddity or an Adaptive Structure? *PLoS ONE*, **6**: 1.

Rochet, M.J., Prigent, M., Bertrand, J.A., Carpentier, A., Coppin, F., Delpech, J.P., Fontenelle, G., Foucher, E., Mahé, K., Rostiaux, E. & Trenkel, V.M. (2008). Ecosystem trends: evidence for agreement between fishers' perceptions and scientific information. *ICES Journal of Marine Science*, **65**: 1057-1068.

Rollet, B. (1981). *Bibliography on mangrove research* 1600-1975. UNESCO, U.K.

Rönnbäck, P. (1999). The ecological basis for economic value of sea food production supported by mangrove ecosystems. *Ecological Economics*, **29**: 235-252.

Rönnbäck, P., Crona, B. & Ingwall, L. (2007). The Return of Ecosystem Goods and Services in Replanted Mangrove Forests – Perspectives from Local Communities in Gazi Bay, Kenya. *Environ. Conservation in press of scientific and indigenous forms of knowledge in the management of natural resources for the future. Environment, Development and Sustainability*, **8**: 467-493.

Ross, M.S., O'Brien, J.J., Ford, R.G., Zhang, K. & Morkill, A. (2009). Disturbance and the rising tide: the challenge of biodiversity management on low-island ecosystems. *Frontiers in Ecology and the Environment*, 7 (9): 471-478.

Ryan, R., Baldridge, B., Schowengerdt, R.A., Choi, T., Helder, D.L. & Blonski, S. (2003). IKONOS spatial resolution and image interpretability characterization. *Remote Sensing of Environment*, **88**: 37-52.

Saenger, P. & Bellan, M.F. (1995). *The mangrove vegetation of the Atlantic Coast of Africa: a review*. Université de Toulouse, Toulouse, France.

Saenger, P., Hegerl, E.J. & Davie, J.D.S. (1983). *Global status of mangrove ecosystems*. commission on Ecology papers n°. 3. Gland, IUCN, Switzerland.

Saenger, P. (1998). Mangrove vegetation: an evolutionary perspective. *Marine and Freshwater Research*, **49**: 277-286.

Saenger, P. (2002). *Mangrove Ecology, Silviculture and Conservation*. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Salas-Leiva, D.E., Mayor-Duran, V.M. & Toro-Perea, N. (2009). Genetic diversity of the black mangrove (*Avicennia germinans* L.) in Colombia. *Hydrobiologia*, **91**: 187-193.

Satapathy, D.R., Krupadam, R.J., Kumar, L.P. & Wate, S.R. (2007). The application of satellite data for the quantification of mangrove loss and coastal management in the Godavari estuary, East Coast of India. *Environmental Monitoring and Assessment*, **134**: 453-469.

Satyanarayana, B., Raman, A.V., Dehairs, F., Kalavati, C. & Chandramohan, P. (2002). Mangrove floristic and zonation patterns of Coringa, Kakinada Bay, East Coast of India. *Wetlands Ecology and Management*, **10**: 25-39.

Satyanarayana, B., Mohamad, K.A., Idris, I.F., Husain, M.L. & Dahdouh-Guebas, F. (2011). Assessment of mangrove vegetation based on remote sensing and ground-truth measurements at Tumpat, Kelantan Delta, East Coast of Peninsular Malaysia. *International Journal of Remote Sensing*, **32**: 6: 1635-1650.

Schaich, H. (2009). Local residents' perceptions of floodplain restoration measures in Luxembourg's Syr Valley. *Landscape and Urban Planning*, **93**: 20-30.

Schlaepfer, R. (2002). *Analyse de la dynamique du paysage*. Fiche d'enseignement 4.2, Laboratoire de Gestion des Ecosystèmes, Ecole Polytechnique de Lausanne, Suisse.

Seher, J. & Tueller, P. (1973). Colour aerial photos for marshland. *Photogrammetric Engineering and Remote Sensing*, **39**: 489-499.

Shearman, P.L. (2010). Recent Change in the Extent of Mangroves in the Northern Gulf of Papua, Papua New Guinea. *Ambio*, **39**: 181-189.

Sherman, R.E., Fahey, T.J. & Battles, J.J. (2000). Small-scale disturbance and regeneration dynamics in a neotropical mangrove forest. *Journal of Ecology*, **88**: 165-178.

Sherman, R.E., Fahey, T.J. & Martinez, P. (2003). Spatial patterns of biomass and aboveground net primary productivity in a mangrove ecosystem in the Dominican Republic. *Ecosystems*, **6**: 384-398.

Shima, L.J. & Anderson, R.R. (1976). The use of aerial color infrared photography in mapping the vegetation of freshwater marsh. *Chesapeake Science*, **17**: 74-85.

Shimatani, K. & Kubota, Y. (2004). Spatial analysis for continuously changing point patterns along a gradient and its application to an Abies sachalinensis population. *Ecological Modelling*, **180**: 359-369.

Simard, M., Zhang, K., Rivera-Monroy, V.H., Ross, M.S., Ruiz, P.L., Castañeda-Moya, E., Twilley, R.R. & Rodriguez, E. (2006). Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data. *Photogrammetric Engineering & Remote Sensing*, **72** (3): 299-311.

Simard, M., Rivera-Monroy, V.H., Mancera-Pineda, J.E., Castañeda-Moya, E. & Twilley, R.R. (2008). A systematic method for 3D mapping of mangrove forests based on Shuttle Radar Topography Mission elevation data, ICEsat/GLAS waveforms and field data:

Application to Ciénaga Grande de Santa Marta, Colombia. *Remote Sensing of Environment*, **112**: 2131-2144.

Sjöling, S., Mohammed, S.M., Lyimo, T.J. & Kyaruzi, J.J. (2005). Benthic bacterial diversity and nutrient processes in mangroves: Impact of deforestation. *Estuarine, Coastal and Shelf Science*, **63**: 397-406.

Smith III, T.J. (1987). Seed predation in relation to tree dominance and distribution in mangrove forests. *Ecology*, **68**: 266-273.

Snedaker, S.C. (1978). Mangroves: their value and perpetuation. *Natural Resources*, **14**: 6-13.

Soares, M.L.G. & Schaeffer-Novelli, Y. (2005). Above-ground biomass of mangrove species. Analysis of models. *Estuarine, Coastal and Shelf Science*, **65**: 1-18.

Sobrado, M.A. & Ewe, S.M.L. (2006). Ecophysiological characteristics of *Avicennia germinans* and *Laguncularia racemosa* coexisting in a scrub mangrove forest at the Indian River Lagoon, Florida. *Trees*, **20**: 679-687.

Souza, A.F. & Martins, F.R. (2005). Spatial variation and dynamics of flooding, canopy openness, and structure in a Neotropical swamp forest. *Plant Ecology*, **180**: 161-173.

Spalding, M., Blasco, F. & Field, C. (1997). *World Mangrove Atlas*. International Society for Mangrove Ecosystems, Okinawa, Japan.

Spalding, M., Kainuma, M. & Collins, L. (2010). *World Atlas of Mangroves*. The International Society for Mangrove Ecosystems, Okinawa, Japan.

Srivastava, S.K. & Binda, P.L. (1991). Depositional history of the Early Eocene Shumaysi Formation, Saudi Arabia. *Palynology*, **15**: 47-61.

Steinke T.D., Ward C.J. & Rajh A. (1995). Forest structure and biomass of mangroves in the Mgeni estuary, South Africa. *Hydrobiologia*, **295**: (1-3) 159-166.

Sullivan, C. (2005). *The importance of mangroves*. Available: www.vi_shandwildlife.com/Education/FactSheet/PDF_Docs/28Mangroves.pdf. Accessed 2009 June 1.

Tamai, S., Nakasuga, T., Tabuchi, R. & Ogino, K. (1986). Standing biomass of mangrove forests in Southern Thailand. *J. Jpn. For. Soc.*, **68**: 384-388.

Tansley, A.G. & Fritsch, F.E. (1905). Sketches of vegetation at home and abroad. I. The flora of the Ceylon littoral. *New Phytol*, **4**:1-1727-55.

Taylor, M., Ravilious, C. & Green, E. P. (2003). *Mangroves of East Africa*. WCMC, Cambridge, UK.

Teas, H.J. (1977). Ecology and restoration of mangrove shorelines in Florida. *Environmental Conservation*, **4**: 51-58.

Thioulouse, J., Chessel, D., Dolédec, S. & Olivier J.M. (1997). ADE-4: a multivariate analysis and graphical display software. *Statistics and Computing*, **7**: 75-83.

Tomlinson, P.B. (1986). *The botany of mangroves* Cambridge: Cambridge University Press, UK.

Tonye, E. & Akono, A. (1998). *Application de la réalité de terrain et de l'imagerie radar à la cartographie des mangroves de la région de Douala*. In : Dubois, J.-M., Bernier, M., Fortin, J.-P. & Boivin, F. (éd), La réalité de terrain en télédétection: pratiques et méthodes, Actes des VII^{ème} Journées scientifiques du Réseau Télédétection de l'AUPELF-UREF, 13-17 octobre 1997, Sainte-Foy, pp. 241-247.

Triest, L. (2008). Molecular ecology and biogeography of mangrove trees towards conceptual insights on gene flow and barriers: a review. *Aquatic Botany*, **89** (2): 138-154.

Turner, M.G. (1989). Landscape ecology: the effect of pattern on process. *Annual Review of Ecology and Systematics*, **20**: 171-197.

Twilley, R.R., Snedaker, S.C., Yanez-Arancibia, A. & Medina, E. (1996). *Biodiversity and Ecosystem processes in Tropical Estuaries: Perspectives of Mangrove Ecosystems. In*: Mooney, H.A.; Cushman, J.H.; Medina, E.; Sala O.E., and Schulze E.-D. (ed.), *Functional Roles of Biodiversity: A Global Perspective*. John Wiley & Sons Ltd. pp. 327-370.

UNEP (2007). *Mangroves of Western and Central Africa* UNEP-Regional Seas Programme/UNEP-WCMC.

UNFCC (2007). *Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December* 2007. Addendum. Part Two: Action taken by the Conference of the Parties at its thirteenth session.

Vaiphasa, C., de Boer, W.F., Skidmore, A.K., Panit-chart, S., Vaiphasa, T., Bamrongrugsa, N. & Santitamnont, P. (2007). Impact of solid shrimp pond waste materials on mangrove growth and mortality: a case study from Pak Phanang, Thailand. *Hydrobiologia*, **591**: 47-57.

Valiela, I., Bowen, J.L. & York, J.K. (2001). Mangrove forests: one of the world's threatened major tropical environments. *BioScience*, **51** (10): 807-815.

Van Campo, E. & Bengo, M.D. (2004). Mangrove palynology in recent marine sediments off Cameroon. *Marine Geology*, **208**: 315-330.

Vannucci, M. (1997). Supporting appropriate mangrove management. *International News Letter of Coastal Management-Intercoast Network*, Special edition **1**: 1-3.

Verheyden, A., Dahdouh-Guebas F., Thomaes K., De Genst W., Hettiarachchi, S. & Koedam, N. (2002). High-resolution vegetation data for mangrove research as obtained from aerial photography. *Environment, Development and Sustainability*, **4**: 113-133.

Villiers, J.F. (1973). Etude floristique d'une mangrove atlantique sur substrat rocheux au Gabon. *Annales de la Faculté des Sciences de l'Université de Yaoundé*, **14**: 3-45.

Vo-Luong, P. & Massel, S. 2008. Energy dissipation in non-uniform mangrove forests of arbitrary depth. *Journal of Marine Systems*, **74**: 603-622.

Walsh, G.E. (1977). *Exploitation of mangrove*. In: Chapman, V.J. (Ed.), Wet Coastal Ecosystems. Elsevier Science, New York, USA.

Walters, B.B. (2003). People and mangroves in the Philippines: Fifty years of coastal environmental change. *Environmental Conservation*, **30**: 293-303.

Walters, B.B. (2005a). Patterns of local wood use and cutting of Philippine mangrove forests. *Economic Botany*, **59**: 66-76.

Walters, B.B. (2005b). Ecological effects of small-scale cutting of Philippine mangrove forests. *Forest Ecology and Management*, **206**: 331-348.

Walters, B.B., Rönnbäck, P., Kovacs, J., Crona, B., Hussain, S., Badola, R., Primavera, J.H., Barbier, E.B. & Dahdouh-Guebas, F. (2008). Ethnobiology, socioeconomics and adaptive management of mangroves: a review. *Aquatic Botany*, **89** (2): 220-236.

Wang, W.Q. & Lin, P. (2003). Element distribution in mangroves and salt tolerance mechanism. *Sci. Silv. Sin.*, **6**: 30-39.

Wang, L., Mu, M., Li, X., Lin, P. & Wang, W. (2010). Differentiation between true mangroves and mangrove associates based on leaf traits and salt contents. *Journal of Plant Ecology*, doi: 10.1093/jpe/rtq008.

Warde, W. & Petranka, J.W. (1981). A correction factor table for missing point-center quarter data. *Ecology*, **62** (2): 491-494.

Warwick, R.M. (1986). A new method for detecting pollution effects on marine macrobenthic communities. *Marine Biology*, **92**: 557-562.

Whigham, D.F., Verhoeven, J.T.A., Samarkin, V. & Megonigal P.J. (2009). Responses of *Avicennia germinans* (Black Mangrove) and the Soil Microbial Community to Nitrogen Addition in a Hypersaline Wetland. *Estuaries and Coasts*, **32**: 926-936.

Wilkie, D.S. (1994). Remote Sensing Imagery for Resource Inventories in Central Africa: The Importance of Detailed Field Data. *Human Ecology*, **22** (3): 379-403.

Wolff, E. (2005). *Télédétection appliquée à la géographie régionale et à l'aménagement du territoire*. Note de cours 2005-2006 GEOG 077, ULB, Bruxelles, Belgique.

Wong, Y.S., Tam, N.F.Y. & Lan, C.Y. (1997). Mangrove wetlands as wastewater treatment facility: a field trial. *Hydrobiologia*, **352**: 49-59.

Wooller, M., Smallwood, B., Jacobson, M. & Fogel, M. (2003). Carbon and nitrogen stable isotopic variation in *Laguncularia racemosa* (L.) (white mangrove) from Florida and Belize: implications for trophic level studies. *Hydrobiologia*, **499**: 13-23.

Zhang, K. (2008). Identification of gaps in mangrove forests with airborne LIDAR. *Remote Sensing of Environment*, **112**: 2309-2325.

2-D	Two Dimentional
ADE	Analysis of Ecological Data
AGB	Above Ground Biomass
APG	Angiosperm Phylogeny Group
ASTER	Advanced Spaceborne Thermal Emission and reflection Radiometer
AWiFS	Advanced Wide Field Sensor
BRIC	Bureau des Relations Internationales et de la Coopération
CAST	Chinese Academy Space of Technology
CBERS	China-Brazil Earth Resource Satellite
CEW	Cameroon Environmental Watch
CI	Complexity Index
CMN	Cameroon Mangrove Network
COPCVAM	Conservation et Valorisation des Mangroves de Mouanko (Cameroun)
COTCO	Cameroon Oil Transportation Company
CWCS	Cameroon Wildlife Conservation Society
DM	Dry Matter
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization
FFT	Fast Fourier Transform (
FOTO	Fourier-based Textural Ordination
GL-AFOLU	IPCC Guidelines for National Greenhouse Gas Inventories - Agriculture, Forestry and Other Land Use
GPS	Global positioning System
HRC	High Resolution Camera
HRV	Haute Résolution Visibles
HRVIR	Haute Résolution Visible et Infrarouge
HSF	High-Stature Forest
ID	Identity
INPE	National Institute for Space Research
IPCC	Intergovernmental Panel on Climate Change
IRMSS	Infrared Multispectral Scanner
IRS	Indian Remote Sensing
IV	Importance Value
LAI	Leaf Area Index

LISS	Linear Imaging Self Scanning Sensor
LSF	Low-Stature Forest
MINEF	Ministère de l'Environnement et des Forêts (Cameroun)
MINEP	Ministère de l'Environnement et de Protection de la nature (Cameroun)
MINEPIA	Ministère de l'Elevage, des Pêches et des Industries Animales (Cameroun)
MINFOF	Ministère des Forêts et de la Faune (Cameroun)
MINMEE	Ministère des Mines, de l'Eau et de l'Energie (Cameroun)
MINTOUR	Ministère du Tourisme (Cameroun)
MINTP	Ministère des Travaux Publics (Cameroun)
MINTRANS	Ministère des Transports (Cameroun)
MODIS	Moderate Resolution Imaging Spectroradiometer
MSF	Medium-Stature Forest
MSS	Multi-Spectral Scanner
NHC	National Hydrocarbon Corporation
nMDS	non-metric Multi-Dimensional Scaling
OM	Organic Matter
ONG	Organisations Non Gouvernementales
PCA	Principal Component Analysis
PCQM	Point-Centred Quarter Method
PRIMER	Plymouth Routines In Multivariate Ecological Research
RADAR	RAdio Detection And Ranging
RCM	Réseau de Conservation des écosystèmes de Mangrove (Cameroun)
REDD	Reduction of carbon Emissions due to Deforestation and forest Degradation
RGB	Red Green Blue
RMS	Root Mean Square
SA	Surface Area
SACC	Surface Area Covered by the Crown
SD	Standard Deviation
SIG	Systèmes d'Informations Géographiques
SONARA	Société National de Raffinerie (Cameroun)
SPOT	Satellite Probatoire d'Observation de la Terre
SPSS	Statistical Package for Social Sciences
SRTM	Shuttle Radar Topography Mission
TM	Thematic Mapper
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

UTM	Universal Transverse Mercator
VHR	Very High Resolution
WFI	Wide Field Imager
WGS	World Geodetic System

LIST OF TABLES

Semi-structured questionnaire used in Chapter 2

Questionnaire N°: …….. **Date:** …..../…..../........ **Name of the market or village:**……………………………………………..

1. SOCIO-DEMOGRAPHIC AND ECONOMIC TRAITS

Sex : M / F **Age / Age class :** …………….

Family status: Bachelor / Married / Widowed

Household size:

	Number
M, adult (> 18 yrs)	
F, adult (> 18 yrs)	
Children (< 18 yrs)	
secondary school	
primary school	
nursery school	
baby	
Others, allied and joint family	

Since how many years are you living here? ……………………………………………………………………………………………………

What is your level of education? less than primary / primary / secondary / high school / university

What is your job? ………..

All year round? ………………..

What is the source of family income by rank of order? 1:……………….……… 2:………..…………… 3:………..………...……..

What is the level of annual income (FCFA) of the family? ……………………………………………………………………………...

Which assets does the family have?

Agricultural land (area and crops) : ……………………………………………………………………………….....................

Trees (# and spp): ……...

Cattle (# and spp): Livestock (cow, ox, buffaloe): …………………………………………………………………………

Small stock (goat, sheep): ………………………………………………………………………………………

Poultry (chicken, ducks, turkey): ……………………………………………………………………………

Boat (#) (with motor?): ……………………………………………………………………………………………......

Bicycle (#): ………....

Motorcycle (#): ……...

Family car (#): ……

TV (#): ………

Fridge (#): ……….....

Gas cooker: ………

Electric cooker: ……………………………………………………………………………………………………….....

Which type of house do you have?

wood & mud / cemented?

wood & coral stone / cemented?

natural stones (white) / cemented?

bricks (grey) / cemented?

Which type of roof do you have?

iron plates

other : ……………..

2. MAIN USES OF THE MANGROVE AS VEGETATION, AS ECOSYSTEM

What do you understand by the term mangrove?

the vegetation, the wood / the whole area, ecosystem

other : ………………..……………………………………………………………………………………………………..

How many species of mangroves do you know? (to estimate the knowledge on the mangroves; CROSS- CHECK with propagules, branches, photos or whatever is available)

0 / 1 / 2 / 3 / 4 / 5 / 6 / 7

Are you dependent on the mangrove forest? Yes / No

What are your main uses of the mangrove by rank of order?

A. Fuelwood (firewood, charcoal,…)

B. Construction and service wood (house, fence, frames, chairs, tables, shelves, utensils,)

C. Others (specify)

2. A. FUELWOOD

What do you use the fuelwood for?

Cooking / Heating

Other: …………..………………………………………..……………………………………………………………

What species of mangroves do you use related to fuelwood by rank of order?

Indicate if it is under the form of firewood (F) or as charcoal (C)

Species	Part used	Quantity	
1.			F – C
2.			F – C
3.			F – C
4.			F – C
5.			F – C

Which are the two best species for burning and what are the criteria and characteristics making the mangrove species appropriate?

First species: ……………………………………..… High calorific value / Little or no smoke / Convenient size / Availability

Second species: ………………………………..…… High calorific value / Little or no smoke / Convenient size / Availability

How do you get the mangrove wood?

Buy (price per quantity: ………….FCFA)

Receive from neighbours / other fishermen as service

Exchange for other goods

Personal collection

If you personally collect, how frequently do you visit the mangrove and at what distance from the town or village?

…………………….. / week

………………….…./ month

whenever you go out for fishing

Distance (or time travelled): ……….km

If you personally collect, who collects the mangrove wood from the forest?

Father / Mother / Children

Others : ……………………..……………………..……………………..……………………..………………….…………

Do you sell mangrove for fuelwood?

No / Yes: price per quantity : …………FCFA

Apart from mangrove firewood or charcoal, which other sources of fuel do you prefer?

Other wood (which spp.: ……………………..……………………..……………………..…………………….……………)

Other charcoal (which spp : …………………...……………………..……………………..…………………………..)

Gas; Kerosine; Electricity

Others………...

If you get the resources continually are ready to stop mangrove destruction?

Yes Completely?...
at slightly higher rate?...
Explain?: …………………..…………………..……………………………………………………..
....
……………………………………………………………………………………….......................
……………………………………………………………………………………….......................

No

I don't know

2. B. CONSTRUCTION AND SERVICE WOOD

Construction wood = house construction and fences
Service wood = furniture, wood carving,…

What species of mangrove do you use related to timber for house construction purposes by rank of order?

Rank	Species	Part used / utilization class	Use
	Rhizophora (red mangrove)		
	Avicennia (black mangrove)		
	Laguncularia (white mangrove)		
	Conocarpus (button wood)		
	Nypa fruticans (palm)		

Which are the two best species for house construction and what are the criteria and characteristics making the mangrove species appropriate?

First species: …………… High durability : ………yrs
Strong / Convenient size / Availability / Aesthetical

Second species: …………… High durability : ………yrs
Strong / Convenient size / Availability / Aesthetical

How do you get the mangrove wood?

Buy price per quantity: ………….FCFA

Receive from neighbours / other fishermen as service

Exchange for other goods

Personal collection

If you personally collect, how frequently do you visit the mangrove and at what distance from the town or village?

…….. / week

…..…/ month

whenever you go out for fishing

Distance (or time travelled): ……….km

If you personally collect, who collects the mangrove wood from the forest?

Father / Mother / Children

Others: ……

Do you sell mangrove poles for construction?

No / Yes: price per quantity: ………….FCFA

Apart from mangrove construction wood, which other materials for construction do you prefer?

Other wood (which spp.: ………………………..………………………..………………………..……………………………..........)

natural stones (white)

bricks (grey)

Other: ………..

If you get the resources continually are ready to stop mangrove destruction?

Yes Completely?...

at slightly higher rate?...

by what ?: ……………………..…………………….…………………………………………………

....

……………………………………………………………………………………………….....................

No

I don't know

What species of mangrove do you use as service wood by rank of order?

Rank	Species	Part used / utilization class	Use
	Rhizophora (red mangrove)		
	Avicennia (black mangrove)		
	Laguncularia (white mangrove)		
	Conocarpus (button wood)		
	Nypa fruticans (palm)		

Do you sell mangrove wood products ?

No / Yes : price per quantity : ………….FCFA

3. EVOLUTION OF THE MANGROVE AREA AND LOCAL IMPORTANCE

How important are the mangroves for your livelihood?

very / a little / not much / not at all important / I don't know

Do you benefit more from the mangrove wood resource or from the mangrove fish resource?

wood fish both I don't know

Are you familiar with any forestry or fishery regulations? If yes, list examples and your opinion on them?

………

………

………

How do you see the future of the mangrove?

………

………

………

Have you noticed any changes in the vegetation mangrove forest during your lifetime?

No

Yes → It has increased !? By what?……………………………………………………………………………………

It has decreased !? By what? ……………………………………………………………………………………..

Remained unchanged!? By what?...

Have you noticed any other changes in this area during your lifetime? Explain?

………

………

………

Semi-structured questionnaire used in Chapter 3

Questionnaire N°: …….. **Date:** …..../…..../...... **Name of the sampling site:**……………………………………………...............

1. SOCIO-DEMOGRAPHIC AND ECONOMIC TRAITS

Sex: M / F **Age / Age class:** …………….

Family status: Bachelor / Married / Widowed

Household size:

	Number
M, adult (> 18 yrs)	
F, adult (> 18 yrs)	
Children (< 18 yrs)	
secondary school	
primary school	
nursery school	
baby	
Others, allied and joint family	

Since how many years are you living here? ……………………..………………………………………..………………………………….

What is your level of education? less than primary / primary / secondary / high school / university

What is your job? …………………………………..………………………………..………………………………………………….

All year round? ………………..

What is the source of family in come by rank of order? 1:………………..……… 2:………..…………… 3:……….………...…...

What is the level of annual income (FCFA) of the family? ……………………………………………………………………...

Which assets does the family have?

Agricultural land (area and crops): ……………………………………………………………………………......................

Trees (# and spp): ……………………………………………………………………………………………………..

Cattle (# and spp): Livestock (cow, ox, buffaloe) : …………………………………………………………………………

Small stock (goat, sheep) : ………………………………………………………......................................

Poultry (chicken, ducks, turkey): ……………………………………………………………………………………....

Boat (#) (with motor?): ……………………………………………………………………………………………………

Bicycle (#) : ………..

Motorcycle (#): ……………………………………………………………………………………………………...

Family car (#): ……………………………………………………………………………………………………….

TV (#): ……..

Fridge (#): ……

Gas cooker: ………...

Electric cooker: ……

Which type of house do you have?

wood & mud / cemented ?

wood & coral stone / cemented?

natural stones (white) / cemented?

bricks (grey) / cemented?

Which type of roof do you have?

iron plates

other : ……....

2. MAIN USES OF THE MANGROVE AS VEGETATION, AS ECOSYSTEM

What do you understand by the term mangrove?

the vegetation, the wood / the whole area, ecosystem

other : ……………….……………………………………………………………………………………………………….

How many species of mangroves do you know? (to estimate the knowledge on the mangroves; CROSS- CHECK with propagules, branches, photos or whatever is available)

0 / 1 / 2 / 3 / 4 / 5 / 6 / 7

What are their vernacular names?...

Are you dependent on the mangrove forest? Yes / No

What are your main uses of the mangrove by rank of order?

A. Fuelwood (firewood, charcoal,…)

B. Construction and service wood (house, fence, frames, chairs, tables, shelves, utensils,)

C. Medicinal & chemical purpose (medicine and ointments,…)

D. Alimentation (food or derived products like honey and alcohol for humans, fodder or feed for or animals)

E. Fishing (boat construction, boat masts, paddles, fishing equipment,…)

F. Others (specify)

<u>2. A. FUELWOOD</u>

What do you use the fuelwood for?

Cooking / Heating

Other : …………..………………………………………………………………………………………………………

What species of mangroves do you use related to fuelwood by rank of order?

Indicate if it is under the form of firewood (F) or as charcoal (C)

Species	Part used	Quantity	
1.			F - C
2.			F - C
3.			F - C
4.			F - C
5.			F - C

Which are the two best species for burning and what are the criteria and characteristics making the mangrove species appropriate?

First species : …………………………………..… High calorific value / Little or no smoke / Convenient size / Availability

Second species : ……………………………..…… High calorific value / Little or no smoke / Convenient size / Availability

How do you get the mangrove wood?

Buy (price per quantity: ………….FCFA)

Receive from neighbours / other fishermen as service

Exchange for other goods

Personal collection

If you personally collect, how frequently do you visit the mangrove and at what distance from your living place?

…………………….. / week

…………………..…./ month

whenever you go out for fishing

Distance (or time travelled): ……….km

If you personally collect, who collects the mangrove wood from the forest?

Father / Mother / Children

Others: ……………………..……………………..……………………..……………………..…………………….……………………

Do you sell mangrove for fuelwood?

No / Yes : price per quantity: …………FCFA

Apart from mangrove firewood or charcoal, which other sources of fuel do you prefer?

Other wood (which spp : ……………………..…………………….……………………..…………………….……………………)

Other charcoal (which spp : …………………..…………………….…………………….…………………………………..)

Gas

Kerosine

Electricity

Others………...

If you get the resources continually are ready to stop mangrove destruction?

Yes Completely?..

at slightly higher rate?..

Explain?: ………………………..………………………..……………………………………………………………

....

……………………………………………………………………………………………………........................

……………………………………………………………………………………………………........................

No

I don’t know

2. B. CONSTRUCTION AND SERVICE WOOD

Construction wood = house construction and fences
Service wood = furniture, wood carving,...

What species of mangrove do you use related to timber for house construction purposes by rank of order?

Rank	Species	Part used / utilization class	Use
	Rhizophora (red mangrove)		
	Avicennia (black mangrove)		
	Laguncularia (white mangrove)		
	Conocarpus (button wood)		
	Nypa fruticans (palm)		

Which are the two best species for house construction and what are the criteria and characteristics making the mangrove species appropriate?

First species: …………… High durability: ………yrs

Strong / Convenient size / Availability / Aesthetical

Second species: …………… High durability: ………yrs

Strong / Convenient size / Availability / Aesthetical

How do you get the mangrove wood?

Buy price per quantity: ………….FCFA

Receive from neighbours / other fishermen as service

Exchange for other goods

Personal collection

If you personally collect, how frequently do you visit the mangrove and at what distance from the village?

…….. / week

…..…/ month

whenever you go out for fishing

Distance (or time travelled): ……….km

If you personally collect, who collects the mangrove wood from the forest?

Father / Mother / Children

Others: ………………………………………………………………………………………………………

Do you sell mangrove poles for construction?

No / Yes: price per quantity: ………….FCFA

Apart from mangrove construction wood, which other materials for construction do you prefer?

Other wood (which spp: ……………………..………………………..……………………..………………………….)

natural stones (white)

bricks (grey)

Other : ….

If you get the resources continually are ready to stop mangrove destruction?

Yes Completely?...

at slightly higher rate?..

by what ?: …………………..……………………..…………………………………………………...

....

……………………………………………………………………………………….........................

……………………………………………………………………………………….........................

No

I don't know

What species of mangrove do you use as service wood by rank of order?

Rank	Species	Part used / utilization class	Use
	Rhizophora (red mangrove)		
	Avicennia (black mangrove)		
	Laguncularia (white mangrove)		
	Conocarpus (button wood)		
	Nypa fruticans (palm)		

Do you sell mangrove wood products?

No / Yes: price per quantity: ………….FCFA

C. MEDICINAL AND CHEMICAL USE

What species of mangroves do you use for medicinal purposes in rank of order?

Species used	Part used	Cure for	Other product that you use to cure the same
1.			
2.			
3.			
4.			
5.			
6.			
7.			

Method of transformation and processing:

1.
2.
3.
4.
5.
6.
7.

When somebody of your family has a particular illness (*e.g. see answer above*), what is the first thing you will do?

use a particular mangrove species as a cure / visit a general physician / visit a witch doctor / pray

other: …...………………….....……………………...……………………...……………………...…………………………….

In your opinion, which treatment has most effect?

use of a particular mangrove species as a cure / visit to a general physician / visit to a witch doctor / pray

other : …...………………….....……………………...……………………...……………………………...……………..

Do you use any chemical properties from mangroves (*e.g.* dyes, poisons,…)?

Species used	Part used	Use
1.		
2.		
3.		
4.		
5.		
6.		
7.		

How do you get the plants for medicinal or chemical use?

Buy price per quantity: ………….FCFA

Receive from neighbours / other fishermen as service

Exchange for other goods

Personal collection

If you personally collect, how frequently do you visit the mangrove and at what distance from your living place?

…….. / week

…..…/ month

whenever you go out for fishing

Distance (or time travelled) : ………m / km

If you personally collect, who collects the mangrove wood from the forest?

Father / Mother / Children / Others

D. ALIMENTATION

What are the main sources of fooder and feed for your animals?

Animals	Sources (type, species, brand)
Livestock (cow, ox,…)	1. …………………………………………………… 2. …………………………………………………… 3. ……………………………………………………
Small stock (goat, sheep)	1. …………………………………………………… 2. …………………………………………………… 3. ……………………………………………………
Poultry (chicken, ducks, turkey)	1. …………………………………………………… 2. …………………………………………………… 3. ……………………………………………………
Other	1. …………………………………………………… 2. …………………………………………………… 3. ……………………………………………………

Do people make food or drink items from the mangrove?

No / Yes:

Species used	Part eaten/drunk	Nutritive value	Frequency
1.			
2.			
3.			

Method of transformation and processing:

1.
2.
3.

3. FISHERY-RELATED ACTIVITIES

What do you collect from the related to fisheries by rank of order?

fish

crabs

shrimps / prawns

bivalves or shells

Oyster

others (eggs, larvae,…) : …………………………………………………………………………………………………....

Which proportion of your catch do you consume (100 % - % consumption = % sale, unless indicated otherwise)?

Catch	% Consumption
fish	
crabs	
shrimps / prawns	
bivalves or shells	
Oyster	
others (eggs, larvae,…)	

Do you cut mangrove roots for oysters' collection?

Yes?.............................

How many roots do you collect each fishing day?

Does the tree fall down after cutting the roots?

No?..........

Which are the best marketable species? Has the number of this species increased or decreased over de last 10 years ? why?

Catch	Best marketable pecies	FCFA kg^{-1}	+ or -	Why?
Fish				
Crabs				
Shrimps				
Bivalves / Shells				
Other				

Are there any species that you used to catch before, but have completely disappeared now?

……

……

……

In general, do you catch more or less than 10 years ago?

more

less

Why? ……..

IF NOT SAID : Do you think this change is related to a change in the mangroves?

No

Yes, which change? ……………………………………………………………………………………………

IN CASE OF FISHERY DECREASE : What would you propose to increase the fisheries again?

……..

4. PERCEPTION OF ENVIRONMENTAL CHANGES IN THE MANGROVE FORESTS

How important are the mangroves for your livelihood?

very / a little / not much / not at all important / I don't know

Do you benefit more from the mangrove wood resource or from the mangrove fish resource?

wood fish both I don't know

Are you familiar with any <u>forestry</u> or <u>fishery</u> regulations? If yes, list examples and your opinion on them?

………

………

………

How do you perceive the future of the mangrove?

………

………

………

Have you perceived any changes in the vegetation mangrove forest during your lifetime?

No

Yes → It has increased in cover!? By what?… ………………………………………………………………………

It has decreased in cover!? By what? …………………………………………………………………………

Remained unchanged in cover!? By what? ……………………………………………………………………

Have you perceived any changes in fauna diversity in the mangrove forest during your lifetime?

No

Yes → It has increased !? Which species? ……………………… By what?……………………………………………...

It has decreased !? Which species? ……………………… By what?……………………………………………...

Have you noticed any other changes in this area during your lifetime? Explain?

……

……

……

How do you perceived the current state of the mangrove forest?

Less degraded!? Explain why?… ……………………………………………………………………………………

More degraded!? Explain why? ………………………………………………………………………………………

Undisturbed!? Explain why? …………………………………………………………………………………………

CONTACT DETAILS

LAST NAME: NFOTABONG ATHEULL

FIRST NAME: ADOLPHE

PLACE AND DATE OF BIRTH: FONGUETAFOU, 20-09-1978

NATIONALITY: CAMEROUNIAN

GENDER: MALE

EMAIL: anfotabo@ulb.ac.be; atheull@yahoo.fr

PHONE: +32 2 650 21 64; +237 33 12 29 92

DIPLOMAS

2002-2003: Bachelor Degree in Natural Science (University of Yaounde I, Cameroon)

2003-2004: Master Degree in Plant Biology (University of Yaounde I, Cameroon)

2004-2006: Advanced University Diploma in Specialized Studies concerning the substainable management of household refuse in Yaounde (University of Yaounde II)
Discipline: *Environment and Urban Habitat*

2006-2008: Master Degree in Sciences concerning mangrove products utilization in Kribi, the Nyong River Mouth and Cameroon estuary (Université Libre de Bruxelles – ULB, Belgium)

2008: First inscription in Ph.D Thesis (Université Libre de Bruxelles – ULB, Belgium / The University of Douala)

PUBLICATIONS

Nfotabong Atheull, **A**., Din, N., Longonje, S.N., Koedam, N. & Dahdouh-Guebas, F. (2009). Commercial activities and subsistence utilization of mangrove forests around the Wouri estuary and the Douala-Edea reserve (Cameroon). *Journal of Ethnobiology and Ethnomedicine*, **5**: 35.

Nfotabong Atheull, **A**., Essomè Koum, L.G., Din, N. & Dahdouh-Guebas, F. (2011). *Mangrove forest structure organisation in a monospecific stand of the black mangrove Avicennia germinans (L.) Stearn in the Cameroon estuary*. Book of abstracts, VLIZ Young Marine Scientists' Day, Brugge, Belgium. VLIZ Special Publication 48.

POSTERS

Flandroy, J., Cunha-Lignon, M., **Nfotabong Atheull**, **A**., Kampel, M., Din N. & Dahdouh-Guebas, F. (2009). Techniques to analyse damaged mangrove forests: Study case for

Cubatão (Brazil) and DOUALA (Cameroon). Marine Sciences: integration for development, ColacMar, Cuba.

Cunha-Lignon M., Mohamed, M.O.S., **Nfotabong**, **Atheull**, **A**., Mukherjee, N., Maniatis, D., Flandroy, J., Kairo, J.G., Din, N., Shanker, K., Koedam, N. & Dahdouh-Guebas, F. (2009). Impacts on urban and peri-urban mangroves and their implications for governance: Case-studies in the Gambia, Cameroon, Kenya, Brazil and India. Proceedings of the Symposium African Botany in Brussels, ULB/VUB, Belgium.

Nfotabong Atheull, **A**., Din, N. & Dahdouh-Guebas, F. (2009). Mangrove propagules predation by gastropod fauna in the Wouri estuary (Cameroon). Young Botanist Day, ULB, Bruxelles.

Nfotabong Atheull., **A**., N. Din & Dahdouh-Guebas, F. (2010). Spatial pattern of *Avicennia germinans* (L) Stearn trees in the Wouri estuary (Cameroon). Young Botanists's Forum. *Cryptogamy in Belgium*, National Botanic Garden, Meise, Belgium.

RESEARCH INTERESTS

Ethnobotany; Forest structure and dynamics; Ecology; Image processing; Coastal ecosystems management.

FIELDWORK EXPEDITIONS IN CAMEROON

2007-2009 Cameroon estuary, Rio del Rey estuary, Nyong River mouth, Kribi

SOFTWARE SKILLS

MS Word, Excel, Access, Powerpoint, Canoco, SPSS, Statistica, PRIMER *v. 6*, R.2.12.2, CorelDRAW X5, Photoshop, ArcGIS 9.3 and ERDAS 9.3.

LANGUAGES

ENGLISH (++), French (+++), Mbo (Parents' tongue)

Adolphe Nfotabong Atheull

Impact of anthropogenic activities on the vegetation structure of mangrove forests in Kribi, the Nyong river mouth and Cameroon estuary

Despite the known/well recognised ecological, biological and economical importance of mangrove ecosystems, these forests are declining fast essentially because of anthropogenic intervention (for agriculture, aquaculture, fuelwood, settlements, etc.). Therefore these vulnerable habitats require continuous monitoring to adapt suitable and sustainable management practices.
The present thesis contains: (a) assessment of mangrove forest products usage, (b) perceptions of the local people on mangrove environmental changes, (c) the changes in mangrove vegetation cover around Douala (Cameroon), (d) reconstruction of the mangrove forest structure prior to wood harvesting, (e) mapping of the diameter distribution, stand biomass and carbon stocks from a non peri-urban mangroves located within the Cameroon estuary, and (f) analysis on the spatial distribution of *Avicennia germinans* (L.) Stearn. The findings are extremely useful for knowing the impact of local population on mangrove vegetation at Cameroon estuary, Nyong river mouth and Kribi. The multi-disciplinary approaches used in this research work are also applicable to other disturbed mangrove forests.

Impacts des activités anthropiques sur la structure de la végétation des mangroves de Kribi, de l'embouchure du fleuve Nyong et de l'estuaire du Cameroun

Bien que globalement reconnues comme des écosystèmes à importance écologique, biologique et économique remarquable, les forêts de mangroves sont soumises à une anthropisation (agriculture, aquaculture, bois de chauffe, habitations, etc.) sans cesse croissante. Ainsi, ces habitats vulnérables requièrent un suivi continu afin d'adapter des mesures de gestion convenable et durable.
Cette dissertation vise à (a) évaluer les divers usages des produits issus des mangroves, (b) analyser la perception des résidents locaux sur les changements environnementaux qui se sont produits dans les mangroves, (c) estimer les changements du couvert végétal des mangroves aux environs de Douala (Cameroun), (d) reconstruire la structure des forêts de mangroves avant les prélèvements de bois, (e) cartographier la distribution de diamètres, de biomasses et de stocks carbonés des mangroves non périurbaines situées à l'estuaire du Cameroun et (f) d'analyser la répartition spatiale d'*Avicennia germinans* (L.) Stearn. Les résultats sont utiles pour le suivi et l'évaluation des impacts humains sur la structure de la végétation des mangroves de l'estuaire du Cameroun, de l'embouchure du fleuve Nyong et de Kribi. L'approche multi-disciplinaire utilisée dans le présent travail peut aussi être appliquée à d'autres forêts de mangroves perturbées.

Biologie des Organismes

Biocomplexity Research Focus

CoTco