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SHELLFISH COLLECTION IN SENEGAMBIAN MANGROVES: A FEMALE KNOWLEDGE SYSTEM IN A PRIORITY CONSERVATION REGION

Judith A. Carney[1]

Shellfish collected in the West African mangrove ecosystem of Senegambia provide a crucial source of dietary protein, but the species harvested for household consumption have received little attention in conservation and socioeconomic research. This study examines the edible mollusks, gastropods, and crustaceans that figure prominently in a mangrove ecosystem that has emerged as a global conservation priority. Based on interviews and field observations, the species that are consumed are identified, as well as the locations within the ecosystem where they are harvested. Attention is also drawn to the gendered practices that inform collection and preservation. Edible shellfish hold considerable potential for monitoring mangrove ecosystem health, which is increasingly affected by deforestation and rising and acidifying seas. This paper highlights the importance of collaborating with local peoples who have cultural and economic ties to mangrove forests and ethnobiological knowledge about the management of these resources, which are essential for the development of effective conservation strategies.

Keywords: *edible shellfish, mangroves, female harvesters, conservation, Senegambia*

Introduction

Many of the world's poor depend upon mangrove ecosystems for subsistence and livelihoods. For these people, shellfish provide a crucial source of dietary protein. Despite their contribution to household and community nutrition, the species collected for household consumption have received little research attention. For example, artisanal shellfish are largely absent from official fisheries statistics unless an export market for a species exists. Despite this, lacuna, mollusks, gastropods, and crustaceans figure prominently among the wild resources that earn mangroves their reputation as "supermarkets of the poor." Moreover, such species provide a means to link local ecological knowledge to scientific concern with mangrove loss, rising sea levels, and ocean acidification.

This study examines the edible shellfish that are critical to household diets in the Senegambian mangrove region of West Africa. The region holds one of the most intact mangrove forests along the Atlantic coast but also hosts deforested mudflats that are severely degraded. Senegambia lies astride one of the world's most productive offshore fisheries, which benefits from the upwelling of nutrient-rich water associated with the Canary Current. Three-quarters of the commercially valuable fish taken from these Atlantic waters rely on the mangrove littoral as spawning sites and nurseries, as do many other marine species, including several that are at risk, such as the African manatee (*Trichechus*

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senegalensis); the African clawless otter (*Aonyx capensis*); and turtles: the green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), and olive ridley (*Lepidochelys olivacea*) (IUCN 2017; Nagelkerken et al. 2008). For these reasons, the Senegambian mangrove ecosystem has emerged as a global conservation priority (Crow and Carney 2012). Since the 2000s, the region has become a focus of mangrove reforestation projects supported by the International Union for Conservation of Nature (IUCN), non-governmental organizations (NGOs), and European companies seeking carbon offset credits. Allied policy initiatives aim to establish marine protected areas from reforested mudflats. But these approaches heighten the risk of conflict when they proscribe the access rights of traditional mangrove user groups. Such restrictions erode local support for conservation and can undermine policy application and goals (Beymer-Farris and Bassett 2012; Cormier-Salem and Panfili 2016).

The growing recognition within the scientific community of mangroves as a coupled natural-human system offers a promising way to circumvent this impasse[1]. This approach, which acknowledges the ecosystem's longstanding human component without prejudging it as inexorably destructive, is bringing attention to the traditional environmental knowledge of its inhabitants (Drew and Henne 2006). As mangroves are at the forefront of scientific concern with rising and acidifying seas, local knowledge holds the potential to make relevant contributions when the capacity to obtain scientific data is absent or weak (Bocco and Winklerprins 2016). By highlighting the local knowledge of female collectors of mangrove shellfish, this article contends that conservation policy objectives can be aligned with those who regularly interact with Senegambian mangroves.

The discussion identifies the edible shellfish species that women collect in the Senegambian mangrove ecosystem and the spatial and temporal parameters that influence harvesting strategies. The intent is to establish a baseline for monitoring longer-term trends in shellfish populations, species composition, and shell formation. This focus on women's ethnobiological knowledge indicates ways their observations can contribute to scientific research on ecosystem recovery of reforested mangrove areas and the effects of ocean acidification on edible shellfish species.

The Threatened Mangrove Biome

Mangrove forests are a threatened ecosystem throughout the tropics. Globally, half of the world's mangroves have disappeared since the mid-twentieth century and one-fifth since 1980 (Corcoran et al. 2007; Spalding 2010; Valiela et al. 2001). Mangrove loss approximates nearly two percent per annum and now exceeds that of terrestrial rainforests (Giri et al. 2011; Polidoro et al. 2010). Over the past twenty-five years, one-third of western Africa's mangroves have been deforested, principally as a result of the demand for firewood and building materials associated with coastal urbanization and infrastructure development, with additional but significant impacts from oil spills and salt and sand mining (Spalding 2010; UNEP 2007). Nonetheless, mangroves provide crucial ecosystem services. They protect low-lying tropical coastlines from storm surges and create a vegetation barrier, or bio-shield, against rising seas (Alongi 2008). The "blue carbon" role of the ecosystem in absorbing carbon dioxide and sequestering large amounts of carbon is of considerable importance to the effort to combat global warming (Chmura et al. 2003; Pendleton et al. 2012).

Scientific concern with the effects of global carbon emissions on ocean acidification has encouraged current interest in shellfish as a marker of ecosystem health. Studies in western Africa have demonstrated their potential as bio-indicators for pollution assessment while drawing attention to the risks that estuary contamination poses for shellfish populations and human consumption of marine organisms (Adebayo-Tayo et al. 2006; Bob-Manuel 2012; Bodin et al. 2011). Shellfish can serve as proxy species for monitoring the effects of ocean acidification on biologically important calcium carbonate minerals. The continuing absorption of carbon dioxide by the earth's oceans lowers seawater pH, which can in turn adversely affect the uptake of these minerals by calcifying marine organisms. Coral reefs are threatened, as is shell formation in bivalves, gastropods, and crustaceans. Since all shelled organisms are at risk, so too is the entire marine food web (NOAA 2016).

Among the seafood taken from the mangrove ecosystem, fish receive disproportionate research attention since much of the catch is diverted to regional and international markets. The diverse shellfish harvested from mangrove waterways and mudflats largely go unreported because they predominantly serve local subsistence needs. Mangrove deforestation and habitat destruction severely undermine these reservoirs of dietary protein upon which coastal populations depend. Forest conversion to aquaculture is a leading cause of mangrove attrition in Asia and Latin America, where commercial shrimp farms serve distant markets (Spalding 2010; UNEP 2007; Valiela et al. 2001). Senegambia offers an instructive contrast. The 1968–73 Sahelian drought caused hyper-salinization of the region's waterways and soils, which triggered the initial mangrove dieback (Conchedda et al. 2011). When precipitation norms returned to the region during the 1980s, some villages responded by replanting degraded areas (Cormier-Salem and Panfili 2016). Their efforts derived from local perception that fish and shellfish availability had declined with mangrove loss. These village-based initiatives, in turn, drew the attention of local NGOs and global conservation organizations interested in restoring regional coverage (Cormier-Salem and Panfili 2016). In the twenty-first century, mangrove reforestation has emerged as a major policy objective of the conservation NGOs involved in Senegambia.

Shellfish provide an essential gauge for assessing whether ecosystem recovery is in fact occurring. Scientific knowledge of traditionally harvested mollusk species is thus a necessary precursor for monitoring the bioproductivity of mudflats that have been replanted with mangroves. An identification of the shellfish collected for food establishes a baseline for engaging local perceptions of changes in abundance and composition over time. Emphasis is on a gendered collection system that illustrates the ways that women's ethnobiological knowledge can complement current scientific concern with mangrove ecosystems.

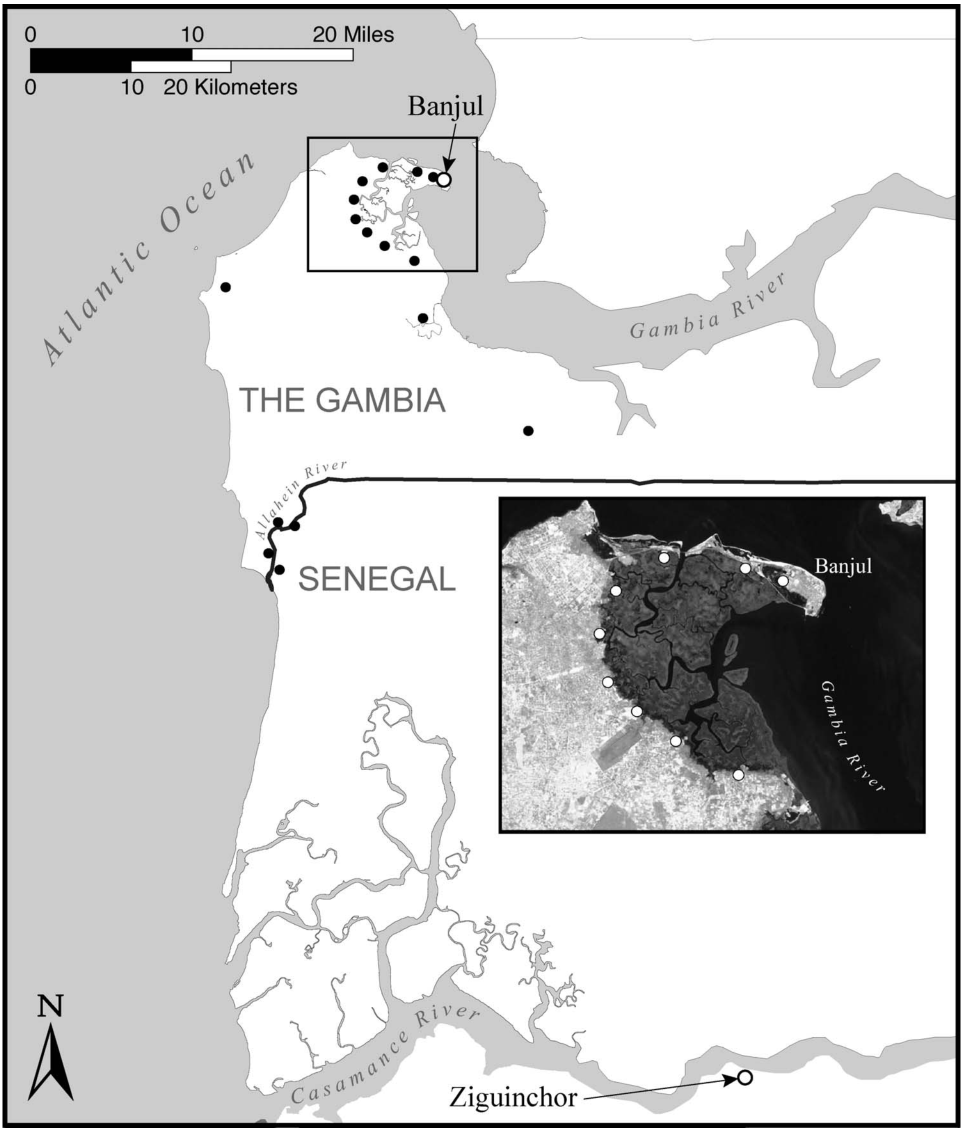

Figure 1. Study area between the Gambia and Casamance Rivers, with shellfish collection sites, and Tanbi Wetlands National Park (inset). Landsat Thematic Mapper bank 4, 5, 3 distinguishes mangroves (in dark grey), 2012, alongside the urbanized Atlantic coastline.

The Senegambian Mangrove Region and Conservation Interventions

The study area is the lowland plain circumscribed by the Gambia and Casamance rivers (Figure 1). It is defined west to east by the mangrove forests that follow the course of these rivers and their principal tributaries, known regionally as *bolongs*. Mangroves extend from the Atlantic coast upstream 160 kilometers (99.4 miles) along the Gambia River and 110 kilometers (68.3 miles) along the Casamance River. The region is located between 13° and 12° north latitude; it includes the Tanbi Wetlands (see Figure 1 insert), one of the most significant mangrove stands in West Africa, and portions of two countries, The Gambia and Senegal (collectively known as Senegambia). The Gambia largely separates Senegal's southern province, Casamance, from its northern extent. The distance along the highway that links the Gambian island capital, Banjul, southward to the international border is about 50 kilometers (31 miles); from there, it is another 96 kilometers (59.7 miles) to Ziguinchor, the provincial capital of Casamance.

Women of the Jola (Dioula: French) ethnic group are the principal collectors of mollusks, gastropods, and crabs in the mangrove forests between the Gambia and Casamance rivers (Pélissier 1966). Shell middens of discarded oyster (*Crassostrea gasar*) and clam (*Senilia senilis*) shells indicate millennia of continuous human habitation of the mangrove littoral (Linares de Sapir 1971). Considered the study region's earliest residents, the Jola constitute ten percent of the Gambian population and are the dominant settlement group of the mangrove forests of Casamance, Senegal. They have evolved a way of life that is adapted to the flora and fauna within their aquatic territory. Jola men fish the coastal waterways and women manage the shellfishery through a common property system that recognizes village claims to proximate harvesting areas. Shared ethnicity, community, and familial ties link Jola communities across the political borders that cross the mangrove region southward from The Gambia through Senegal to Guinea-Bissau.

The study area exhibits a tropical climate with a distinct wet and dry season, which in turn influences mangrove shellfish collection. The rainy season begins in June and typically lasts into October. Annual precipitation averages 1000 mm (39 inches) south of the Gambia River, increasing to 1250 mm (49 inches) in Ziguinchor (Carney et al. 2014; Conchedda et al. 2011). The low gradient of the Gambia and Casamance rivers influences regional mangrove coverage by allowing marine water to advance considerable distances upstream and along associated tributaries. Precipitation cycles, marine currents, diurnal tides, and saline water concentration profoundly mediate human and biotic adaptation throughout the study area. Jola women recognize distinct types of mangroves and associated waterscape habitats that support specific shellfish species.

The mangrove forest is not uniform. The ecosystem is dominated by the red *Rhizophora* mangrove (*R. mangle*, *R. harissonii*, *R. racemosa*), which grows alongside the waterways and reaches 6–7 meters (20–23 feet) in height. *Rhizophora* is recognizable by its distinctive stilt roots, which fan out from the trunk, finger-like, into the water. It is the ecosystem's pioneering species; the roots trap suspended sediments and build soil, thereby stabilizing the low-lying Atlantic coastline from the erosive effects of storm surges. The root system provides fish and other marine species vital spawning grounds and nurseries to raise their young, while anchoring colonies of wild *C. gasar* (commonly known as mangrove or cupped) oysters that are significant in the regional diet. *Rhizophora* forests harbor other species of edible snails (*Cymbium senegalensis*, *Hexaplex duplex*) and crabs (such as the blue crab, *Callinectes sapidus*). The black mangrove, *Avicennia* *germinans,* grows in the hyper-saline soils outside the reach of daily tides and sends up aerial roots (pneumatophores) from the soil below that enable the tree to survive the high salt concentration of its substrate. Other species within the Senegambian mangrove forest are *Laguncularia racemosa*, the white mangrove, and *Conocarpus erectus*, the grey mangrove. However, the majority of shellfish consumed in the study region are associated with the pronounced tidal regime of *Rhizophora* forests.

When Senegambian villagers took the initiative to reforest damaged swampland in the decades after the Sahelian drought, they focused on the *Rhizophora* mangrove, which had been decimated by hypersaline waterways. Donor reforestation projects this century have similarly emphasized *Rhizophora* plantings. These projects are concentrated in two broad areas of the study region: western Gambia north of the international border with Casamance, Senegal, and within the latter, on degraded mudflats north of Ziguinchor. An estimated 14,000 hectares (34,595 acres) of *Rhizophora mangle* have been replanted in Senegal, with perhaps an additional 300 hectares (741 acres) in The Gambia (Carney at al. 2014; Cormier-Salem and Panfili 2016). Initiatives are also underway to expand *Avicennia* coverage since the tree's snorkel-like pneumatophores desalinate soils and so promote swampland reclamation and ecosystem recovery.

These Senegambian reforestation initiatives are part of an international conservation strategy to protect a globally important offshore fishery and marine habitat designated by the IUCN as the West African Marine Ecoregion or WAMER. The aim is to establish one or more marine protected areas (MPA) within WAMER that would include the supporting mangrove forests along the Atlantic littoral from The Gambia southward to Senegal and Guinea-Bissau. Successful lobbying of the Gambian government achieved a critical milestone in 2008 when the 6300-hectare (15,568-acre) Tanbi Wetlands was made a national park (Crow and Carney 2012). This placed one of West Africa's largest intact mangrove stands under protection. Occupying the southern portion of the Gambia River estuary, The Tanbi Wetlands National Park (TWNP) abuts the country's densely populated Atlantic corridor. The TWNP is easily distinguishable from the surrounding urban conurbation in the Landsat image that appears as an inset in Figure 1. The dots on the map indicate Jola villages, which have retained customary access rights to Tanbi waterways, fishing areas, and shellfish collection sites within the national park.

Mangrove reforestation and protection initiatives in the study area currently enjoy the cooperation of traditional user groups. But resource conflict is inevitable if conservation organizations prioritize biodiversity protection over its human denizens and restrict their access to customary sources of food and livelihoods (Beymer-Farris and Bassett 2012; Cormier-Salem and Panfili 2016). Acknowledgment of the mangrove ecosystem as a coupled natural-human system suggests the need for innovative approaches to conservation, such as those the Worldwide Fund for Nature (WWF) developed in the TWNP during the 2009–2014 Gambia–Senegal Sustainable Fisheries Program (GSFP). Instead of promoting the "fortress conservation" paradigm in Tanbi, the GSFP supported the customary access rights of Jola villages to the TWNP. It also encouraged female shellfish collectors to monitor nearby waterways against incursions by outsiders who illegally enter the park to cut *Rhizophora* trees for firewood and building poles. In return for their cooperation, the women were taught formal oyster culture and provided assistance with market development for their expanded harvests (Crow and Carney 2012). This study builds upon the perspective of mangroves as a natural-human ecosystem and focuses on the local ethnobiological knowledge whose practitioners are potential assets for conservation initiatives.

Such forms of collaboration with women shellfish collectors might also contribute to climate-change research. Global warming models that predict rising sea levels place Senegambia's low-elevation coast at particular risk in the coming decades. The Gambian capital is a mere five meters (16.4 feet) above sea level, while nearly 40 percent of the country's population (of 1.8 million) reside along the country's vulnerable Atlantic littoral (Carney et al. 2014). A comparative assessment of the impact of climate change on national fisheries place both Senegal and The Gambia in the top quartile of countries whose economies are most vulnerable under current scenarios (Allison et al. 2009). Against this threat, mangroves provide a protective barrier against storms and rising seas, as well as a source of dietary protein for the regional population. Women's ethnobiological knowledge of the mangrove shellfishery and observations of trends in shellfish catches and morphological change are potentially relevant to scientific interest in the effects of global warming and ocean acidification on shell-forming marine organisms.

Methods and Study Sites

This study results from two periods of fieldwork in Senegambia. The initial fieldwork period from December 2009 to January 2010 involved establishing contacts with the director and key personnel of the Gambian NGO *TRY*, an association of 500 female oyster collectors from 16 Gambian villages, founded in 2007. Interviews with the director and three fisheries experts affiliated with *TRY* were followed by site visits to sixteen participating villages, including nine near the Tanbi Wetlands National Park and four others along the Allahein River international border (Figure 1). Visits were also made to mangrove reforestation projects in Senegal north of the Casamance River.

The second period of fieldwork (November-December 2015) included 15 interviews with government, non-governmental, and donor agency officials who are involved in Gambian mangrove reforestation. Site visits were made to replanted areas and seventeen male and female villagers were interviewed about perceptions of ecosystem recovery. Female respondents framed their responses not just in terms of oysters, but also in terms of other shellfish species, revealing both the significance of these food sources to the household diet and the gendered basis of harvesting. A group meeting with 31 female representatives from thirteen *TRY* oyster association villages was held to elucidate the broader context of shellfish harvesting. This resulted in follow-up visits to participating villages and invitations to visit collection sites.

Fieldwork involved a qualitative participatory approach, with research questions centered on an identification of the edible specimens women collect, the habitat of each species within the mangrove ecosystem, collection and preservation strategies, and marketing opportunities and challenges. Visits were made to wild and formal *C. gasar* oyster culture sites, the boat landings where oysters and cockles (*Senilia senilis*) are processed, and to active harvesting sites of other shellfish species. Interviews were conducted in English and French, and, through interpreters, in Wolof, Jola, and the Crioulo language of Guinea-Bissau.

Visits to key collection sites enabled the identification of species by vernacular names and the specimen's precise habitat (e.g., subtidal, intertidal, mud flats, sand banks) amid daily tidal flows. Site visits occurred during low tide, when many species are exposed and female collectors are most active. Harvested specimens were photographed and their vernacular names recorded in the Wolof and Jola languages for later assistance in identifying the Latin binomials.

Fieldwork commenced at the beginning of the dry season, when women are actively gathering shellfish. The work calendar of Jola women is strongly defined by seasonality. During the rainy season months from June to October, they are involved in rice cultivation. When the rains cease, they plant vegetables on clay soils with water from shallow wells. Sweet potatoes (*Ipomoea batatas*), tomatoes (*Solanum lycopersicum*), bitter tomato (*Solanum incanum*), the African eggplant (*Solanum aethiopicum*), cowpea (*Vigna unguiculata*), okra (*Abelmoschus esculentus*), sorrel (*Hibiscus sabdariffa*), and chili peppers (*Capsicum* spp.) are commonly cultivated. Oil palms (*Elaeis guineensis*), which grow near mangrove swamps, provide the principal cooking oil. During the dry season, women crush the fruit and nuts and extract the palm oil for cooking and sale.

Results

Shellfish collectors in the study area are principally Jola women between the ages of 25 and 60. Many are divorced or widowed with little formal education. Others are migrants who have fled political instability in Casamance and Guinea-Bissau to resettle among relatives in Gambian Jola villages. Shellfish harvesting is one of the few economic activities open to these displaced female migrants.

One study of shellfish consumed in Guinea-Bissau indicates that women collect 22 different species from the WAMER mangrove ecoregion for subsistence and sale (Regalla and Baldé 2008); other reports from Senegal identify an additional 11 edible species (Ba et al. 2006; Guiral at al. 1999). The combined list of 33 species is found online in Supplemental Table 1. Village interviews and visits to harvesting sites in this study area indicate the underlying importance of seven species in women's subsistence collection and market sales. These shellfish are listed in terms of their rank in dietary importance in Table 1. Images of the top five preferences are shown in Figures 2–4. All but the razor clam (*Tagelus adansonii*) and the periwinkle (*Tympanotonos fuscatus*) were observed being harvested during fieldwork. The female informants who provided information

Table 1. Principal shellfish species collected for food in the Senegambian mangrove ecosystem, listed in order of dietary importance.

Shellfish	Species	Vernacular name W=Wolof C=Crioulo	
cupped or mangrove oyster	*Crassostrea gasar*	*yoxos*	W
cockle, blood ark, clam	*Senilia senilis*	*pagne*	W
whelk, mélogène	*Pugilina morio*	*tuffa*	W
sea snail, volute	*Cymbium senegalensis*	*yeet*	W
sea snail, rock snail	*Hexaplex duplex*	*tuffa*	W
razor clam	*Tagelus adansonii*	*lingron*	C
periwinkle, mud creeper	*Tympanotonos fuscatus*	*oupousa*	C

Source: Carney fieldwork 2015.

on these two species were from Guinea-Bissau, so the vernacular names are listed in that country's Crioulo language.

In a report on the Gambian shellfishery, Niang (2009) provided an estimate of the relative proportion of each species in the shellfish take. Subsistence harvests typically included whelk (*Pugilina morio*) (left side, Figure 2), cockle (*S. senilis*) (Figure 3), oysters (*C. gasar*) (Figure 2), sea snail (*Cymbium senegalensis*) (right side, Figure 4), and rock snail (*H. duplex*) (left side, Figure 4). Whelk constituted nearly

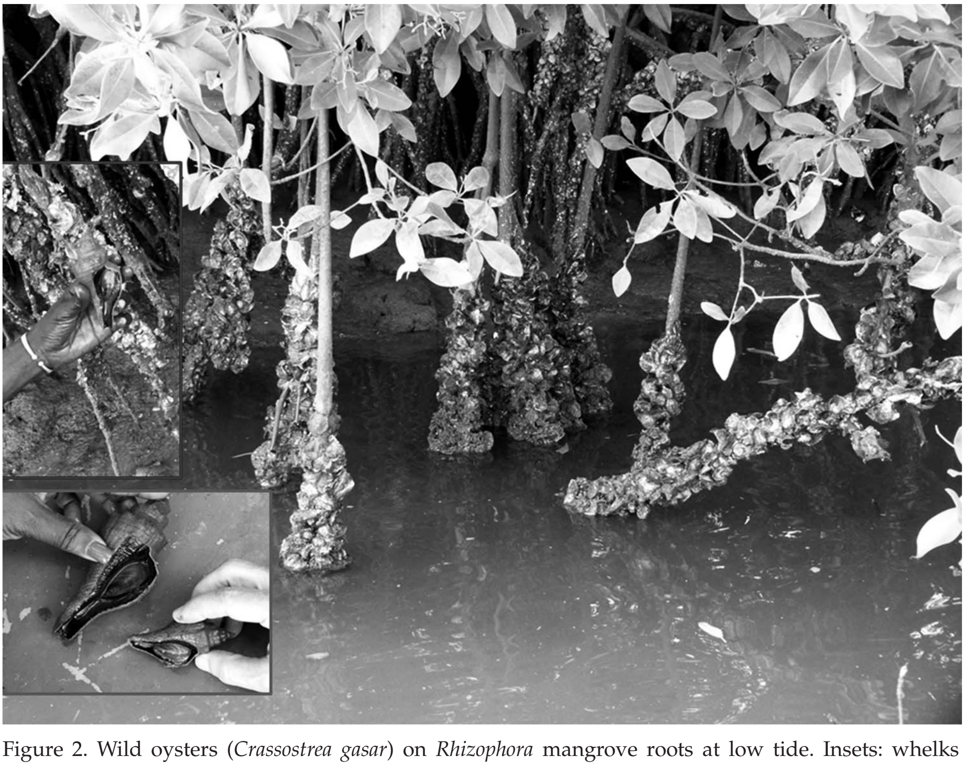

Figure 2. Wild oysters (*Crassostrea gasar*) on *Rhizophora* mangrove roots at low tide. Insets: whelks (*Pugilina morio*) are also collected from this habitat. Photo by Richard Rosomoff.

Figure 3. Cockle (*Senilia senilis*) harvesting on mudflats during low tide. Photo by Fatou Janha Mboob. Inset: pile of cockles after harvesting and waiting to be steamed for family consumption or sale.

Figure 4. Left: the rock snail *Hexaplex duplex* (above), with drying meats (below). Right: the sea snail, *yeet* (*Cymbium senegalensis*), emerges from its shell after collection. Photo by Richard Rosomoff.

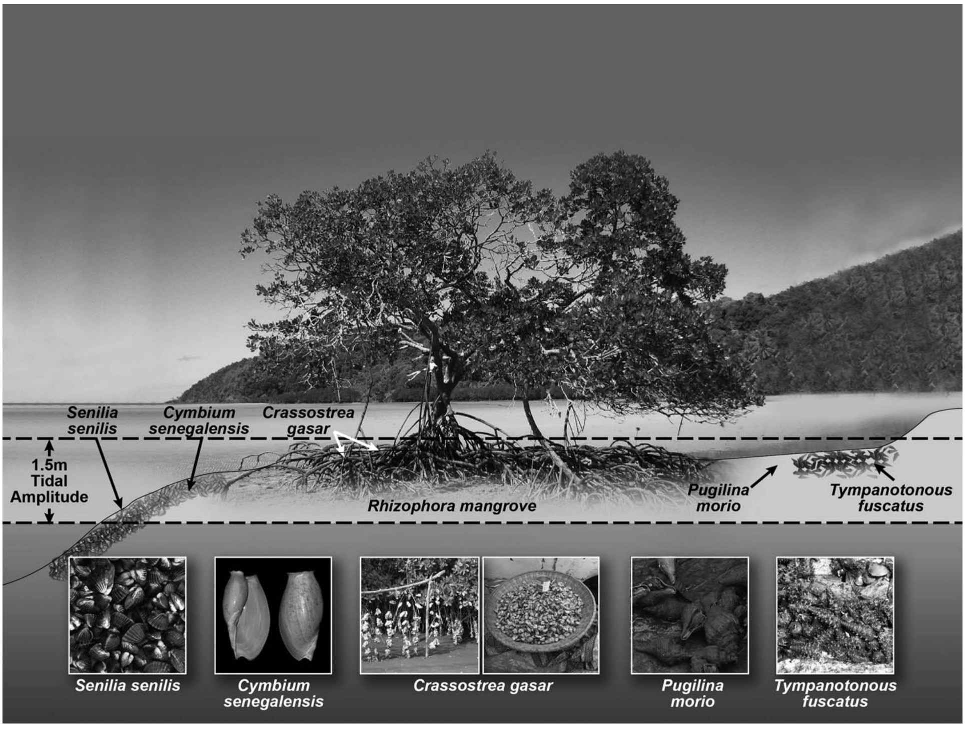

Figure 5. Spatial location of five edible shellfish species in the Senegambian mangrove ecosystem.

a third of women's harvest, followed by cockles (27%) and oysters (20%), while the remainder of the species collected were evenly divided between *Cymbium* and *Hexaplex* snails. Interviews with female collectors in this study indicate the continuing importance of these species in local diets but a shift in their relative ranking in nutritional importance. Oysters are now the most commonly harvested subsistence shellfish in the study area, followed by cockles, the whelk, and the *Cymbium* sea snail.

Commercialization is another discernible trend in the mangrove shellfishery. For example, export markets have developed in Senegal for sea snails (Ba et al. 2006). Asian wholesalers now buy *Hexaplex* rock snails for sale in China. Local harvesters sell the snails to intermediaries, who extract the meat from the shells, then salt and sun-dry it on racks for 3–4 days before trucking it to Dakar (Figure 4). There is also demand for the *Hexaplex* operculum, or valve; it is sold in the Middle East as an ingredient for the manufacture of incense (Supplemental Figure 1). Overseas sales thus reduce the snail's significance to household diets by diverting it from local populations to long-distance markets that offer higher prices. The growing international demand for the rock snail clarifies why local consumption of *Hexaplex* has declined in the study region and male fishermen have largely assumed control of this shellfishery species.

Nonetheless, Jola women remain in control of oyster commercialization. Oysters are exported to Europe as a consequence of donor projects (for example, by the WWF and the NGO *TRY*) that have promoted formal oyster culture to improve female income-earning opportunities. These initiatives start with a natural market advantage: tropical oysters mature in half the time as those raised in temperate climates and can be more quickly harvested. In Senegambia, oysters reach full maturity in the final months of the dry season. Women's knowledge of where wild oysters are abundant has enabled the development of formal oyster culture near associated *Rhizophora* mangrove stands (Supplemental Figure 2). Formal culturing methods involve placing wooden poles or racks in the mudflat from which strings of discarded oyster shells are suspended. When the wild oysters reproduce, the swimming larvae settle on the shells, where they attach and mature. The cultured oysters are harvested and then steamed to open the shells and cook the meats. *TRY* is currently assisting association members with advanced processing methods, such as packaging the oyster meats in vacuum-packed bags for export to Europe. Mangrove oysters remain plentiful; they are both readily available for family consumption and purchase in regional markets, where they are typically sold in 150 gram (5.3 ounce) condensed milk tins (Supplemental Figure 2)[2]. This regional demand results in copious mounds of discarded shells that accumulate at women's processing sites. There is also a market for these shells, which are purchased by dealers who crush and burn them to produce whitewash, fertilizer, mortar for construction, and chicken feed.

The Senegambian shellfishery is undergoing change in response to commercialization of some species and new markets for others. But female harvests continue to provide most of the dietary protein consumed by their families. Women's ethnobiological knowledge informs not just the species that are edible within the mangrove ecosystem but also their habitat and methods of preparation for consumption.

Despite the significance of mangrove shellfish for Senegambian coastal populations, there is little information on the micro-environments from which individual species are collected. Interviews and visits to collection sites aimed to illuminate the ecosystem dynamics that mediate collection practices. To the untrained eye, the mangrove forest appears as an impenetrable tangle of sodden thickets and biting insects. Venturing into this waterscape in motorized canoe, one encounters a labyrinth of meandering river channels with islands, mudflats, and sandy beaches alternately exposed and submerged by the daily tides. This perspective of an amphibious territory obscures the complexity of micro-habitats that sustain the diverse species of shellfish women harvest in the study area (Figure 5).

Women collect two species from the subtidal zone. Cockles (*S. senilis*) are harvested from mud and coarse-sand substrates at low tide (Figure 3). Women recognize that cockles prefer a location along the waterscape away from strong currents. Razor clams (*Tagelus adansonii*), also collected from the subtidal zone, position themselves in underwater burrows along *bolong* channel slopes in tunnels 30–40 cm (12–16 inches) below the waterline substrate. There, they can quickly retreat from threats. Female interviewees consider the collection of razor clams an especially skilled practice but only a few are adept at capturing them.

The other shellfish are harvested from the intertidal zone. Dominating the waterscape is the West African mangrove or cupped oyster (*C. gasar*), the wild species that affixes to the prop roots of the *Rhizophora* mangrove (Figure 2). The rising tide delivers the phytoplankton upon which the oysters feed. Women observe that oyster reproduction is attuned to the seasonal concentration of salt in mangrove waterways, which is at its highest during the late dry season. With the onset of the rains in June, women cease oyster harvesting so that newly released spat have a chance to develop.

Another important edible species of the intertidal zone is *P. morio*, the predatory whelk, which shelters in *Rhizophora* mudflats to which it is camouflaged (Figure 2). Women harvest whelk in conjunction with wild oysters during low tides. The sea snail, *C. senegalensis*, known colloquially as *yeet*, is exposed on mudflats during ebb tides (Figure 4, right). It is prized by women collectors for the savory flavor its fermented meat lends to traditional dishes. The brackish water of the mangrove estuary also supports a small sea snail, the West African periwinkle (*T. fuscatus*), which is shown in Figure 5. The periwinkle is widely consumed in seafood consommés by coastal populations. Because of its vulnerability to organic pollutants, pesticide runoff, and bio-accumulation of toxins, several studies utilize the periwinkle as a bio-indicator of mangrove ecosystem health (Adebayo-Tayo et al. 2006; Bob-Manuel 2012). Another significant edible shellfish of the study area is the *Hexaplex* sea snail, which clings to the rock outcrops that appear in the lower portion of mangrove estuaries and along the Atlantic coast (Figure 4, left). More readily reached by motorized fishing boats, female collectors have now largely ceded *Hexaplex* collection to better equipped male fishermen.

Interviews with women collectors indicated how they coordinate mangrove harvesting strategies with daily, lunar, and seasonal water fluctuations. Mean tidal amplitude averages between 1 and 1.5 meters (39 and 59 inches) in the river estuaries but can reach 2.5 meters (8.2 feet) during full and new moons. Shellfish collection strategies are influenced by precipitation, tidal currents, seasonal variation in water salinity, and the extent of tidal inundation. Women navigate the aquatic territory of the mangrove ecosystem by the diurnal rise and fall of water levels, which are higher during full and new moon lunar cycles and during the rainy season. They depart to gathering sites with the retreating tide, timing their arrival when the heterogeneous mudflat substrates—the sandy, sandy-clay, and clay sediments that host the edible species—are fully visible. Shellfish collection is principally concentrated in the seven-month dry season, after the rice crop has been harvested. The dry season is also an optimal time for preserving shellfish meats by sun drying.

Women frequently reach oyster and crab sites by dugout canoe and paddle (Supplemental Figure 3). Their journey is closely attuned to lunar cycles so that departures are synchronized with ebb tides and returns to flood tides. The geographical reach of their journey along mangrove waterways depends upon a six-hour diurnal tidal cycle that must begin and end during daylight; travel under cover of darkness is neither feasible nor safe. During the rainy season, river and *bolong* water levels swell. The risk of sudden rainstorms and lightning make canoe travel to shellfish sites too hazardous to undertake with any regularity.

Interviews with female oyster collectors indicate that a typical workday keeps them away from their homes for 4.5 to 5 hours, which is consistent with the duration of diurnal tidal cycles that govern harvesting practices. The director of *TRY* estimates women travel between 3 and 8 kilometers (1.9 and 5 miles) to collection sites (Fatou Jahna Mboob, personal communication, December 1, 2016). Female gatherers typically work six days a week. The work week consists of two cycles of collecting and processing. In each cycle, women collect for two consecutive days; the third day is spent processing the harvested shellfish. Oystering is for the most part seasonal. The harvest is adjusted to the duration of the rainy season and completion of farming activities. Fieldwork confirms the conclusions of previous studies, which indicate that shellfish collection takes up 120 to 180 days of the year (Grandcolas 1997; Njie and Drammeh 2011). Cormier-Salem (1986) estimated that, in the decade following the Sahelian drought, Jola women in Senegal's Casamance province collectively harvested as much as 10,000 metric tons (11,023 US tons) of oysters (with shells) annually. A decade later, Grandcolas (1997) reported that female collectors in Senegal's Sine-Saloum region (located north of The Gambia) typically produced 3 kilograms (6.6 lbs.) of sun-dried oyster meats from a daily harvest, or 12 kilograms (26.5 lbs.) weekly, during the dry season. These figures accord with a recent survey of oyster collection in The Gambia, which calculated an average take per canoe trip of 11.5 kilograms (25.4 lbs.) of oysters (with shells), yielding 2.5 kilograms (5.5 lbs.) of edible meat after steaming (Belhabib et al. 2016).

Female interviewees state that mollusks and gastropods are seldom consumed raw. Post-harvest processing is necessary to preserve shellfish in the region's hot and humid tropical climate and for extending the number of months the meat can be stored for subsistence consumption (Madge 1994). Jola women have developed diverse preservation techniques, such as sun-drying, smoking, salting, fermentation, boiling, or steaming. A growing market demand for oysters and cockles favors boiling or steaming since the high heat naturally opens the shells and allows easy extraction of a cooked, saleable product. Although labor-saving, this method increases anthropogenic pressure on regional forests for fuelwood (Carney et al. 2014; Crow and Carney 2012).

Edible gastropods—the sea and rock snails and whelk—require additional processing, such as salting and sun-drying, prior to consumption. The *Cymbium* sea snail, or *yeet*, exemplifies women's complex mastery of food preservation in a tropical climate (Figure 4). The flesh is removed from the shell and cut into parts. The meats are then placed in a jute bag or sack and allowed to ferment for 2–4 days before being washed and sun-dried to arrest the growth of putrefying bacteria. The product obtained, also called *yeet*, is a strong smelling ingredient that lends dishes an umami flavor. *Yeet* is an indispensible component of the Senegalese national fish and rice dish, *thiéboudiène*.

Discussion

In Senegal and The Gambia, the amount of protein in the average person's diet is quite low by standards in other parts of the world: 59 grams (2.1 oz.) per person per day in Senegal or 21.5 kilograms (47.4 lbs.) per annum and 55 grams (1.9 oz.) daily per capita or 20 kilograms (44 lbs.) annually in The Gambia. These figures contrast significantly with data from developed countries, where the average per capita protein intake is 103 grams (3.6 oz.) daily or 37.6 kilograms (82.9 lbs.) per annum (CBSCT 2011). In Senegambia, the proportion of dietary protein derived from marine invertebrates compared to meat has been estimated at 62% for The Gambia and 47% for Senegal (Venugopal 2008:51). These figures underscore the nutritional significance of marine protein in the study region and the mangrove ecosystem that provides it.

The well-developed regional markets that exist for artisanal fish catches leave little protein from this sector for local consumption. Regional fish supplies are also jeopardized by the inability of WAMER countries to enforce protection of their offshore fishery from factory fleets of other nations, whose illegal catches greatly deplete availability for African consumers (Belhabib et al. 2016; Gegout 2016; Pauly et al. 2014). This trend underscores the significance of shellfish, and women's collecting practices, for the nutritional needs of households within the study area.

The edible shellfish species discussed in this study hold promise as potential bio-indicators for monitoring mangrove ecosystem health and the effects of warming and acidifying oceans in the West African Marine Ecoregion. The reseeding of Senegambian mudflats with *Rhizophora* propagules has notably restored mangrove coverage in the study region (Carney et al. 2014; Cormier-Salem and Panfili 2016). As these forests rebound, the expectation is that ecosystem productivity will recover to former levels. At this juncture, more data are needed to assess whether mangrove regeneration is prompting a return of fish and shellfish populations to previously known levels. Some study interviewees thought that shellfish populations were improving in replanted areas, but no evidence for these claims could be established. A recent study from Senegal questions whether bioproductivity is indeed being restored in reforested areas (Conchedda et al. 2011).

Women's ethnobiological knowledge provides an opportunity to bring local observations in conversation with scientific interest in the mangrove ecosystem at regional and global scales. The females involved in the Senegambian mangrove shellfishery are well positioned to provide qualitative assessments of changes in shellfish populations and species composition that can complement conservation concern with ecosystem recovery and health. The effects of global carbon emissions on ocean acidification and shell-forming species present a similar opportunity for connecting local knowledge to climate science research. What makes such collaborations worthwhile is the focus on a subset of shellfish affected by global and regional patterns of environmental change that also provides human populations with vital dietary protein. Viewing the Senegambian mangrove shellfishery as a coupled natural-human system brings the ethnobiological knowledge of traditional users into consideration, while engaging them at the frontlines of conservation and climate change research.

Notes

[1] This is illustrated in the recent funding emphasis by the U.S. National Science Foundation on The Dynamics of Coupled Natural and Human Systems (CNH).

[2] In December 2015, a tin of oysters sold for about 55 cents (U.S.) in Gambian markets.

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