Caution Bay Studies in Archaeology 1

Archaeological Research at Caution Bay, Papua New Guinea

Cultural, Linguistic and Environmental Setting

Edited by

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Chapter 7.
The Natural Setting of Caution Bay: Climate, Landforms, Biota, and Environmental Zones

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Introduction

In this chapter, we review the present and past environment of Caution Bay set in a broader geographical context, including both terrestrial and marine habitats. Our primary objective is to sketch the general canvas upon which the past 6,000 or so years of local human presence, as represented by the Caution Bay archaeological record, played out. A secondary objective is to document the range of contemporary landforms and explore the spatial distribution and ecological dynamics of the various plant and animal communities that still occupy the present landscape, or did so at the time when Europeans first arrived in the 1870s. Knowledge of the contemporary landscape and its resources represents the starting point for inferring continuities and changes in ways of life for the region's past inhabitants as these are tracked back from the present to the mid-Holocene, and ultimately for understanding the choices people made as they balanced various primary extractive and commercial activities to maintain cultural practices, adopt and develop new ones, survive and prosper. Relationships between people and locales at Caution Bay were, and continue to be, dynamic, with people playing a major role in shaping both the physical and biological landscape, just as the landscape and its resources have influenced the course of human history in this area.

Our geographic scope in this chapter extends outside the Caution Bay study area where this is required for interpretative context or to include all of the habitats that could have been exploited directly by people residing at Caution Bay or by other populations involved in local exchange networks.

Location and General Topography

Caution Bay is a shallow coastal basin located 25km northwest of Port Moresby (Figure 7.1). The bay is gently curving and faces to the southwest. It is bounded to the southeast by Boera Head and an outer barrier reef that lies offshore of Boera and Porebada villages; and to the northwest by Lagada 'Island' that is connected to the mainland by low-lying swampy terrain and which bears the prominent landmark of Redscar Head as well as the village of Kido. The coastal villages of Papa and Lea Lea are located in the central part of the bay, just north of the archaeological study area.

Two major estuaries are present within Caution Bay, Vaihua River in the south and the much broader Lea Lea River to the north (Figure 7.1). Together these represent the points of egress of much of the onshore fluvial catchment of Caution Bay, which on average extends inland only 10km from the coast. Further inland, stream flow is initially directed inland where it joins the catchment of the Laloki River, a large perennial river that flows to the northwest, paralleling the coast, before it debouches into Galley Reach in Redscar Bay to the north of Caution Bay.

The complex drainage pattern of the hinterland of Caution Bay is a product of regional uplift and deformation of a broad coastal plain that extends inland for 30 to 40km. Inland of the Laloki River (Mabbutt 1965), the coastal plain rises to meet the foothills of the Owen Stanley Range, a massif with peaks rising to more than 3000m above sea level (a.s.l.) in the region. The coastal plain behind Caution Bay supports a variety of different landforms and habitats, including alluvial plains and swamps, plateaus and undulating hills, and elevated ridges that rise locally to a maximum of 320m a.s.l.

The marine environment of Caution Bay features a more or less continuous nearshore 'fringing' reef, and an outer 'barrier' reef that is restricted to the southwest of the bay (Figure 7.1). The fringing reef commences anywhere from 100m to 700m offshore and varies in width from 150m to 400m. Between the reef and the shoreline is a protected lagoon with a substrate mosaic of open sandy and muddy patches and areas of seagrass meadow (Figure 7.2). The fringing reef is absent from the central portion of Caution Bay, in the vicinity of Papa and Lea Lea villages, probably due to the higher sediment load and greater turbidity caused by outflowing water and alluvial sediments in this part of the bay.

From just south of Papa village the fringing reef creates a well-protected shoreline that today supports a more or less continuous belt of mangroves that extends to

Figure 7.1. Distribution and extent of offshore barrier reef and the fringing reef at Caution Bay (Sources: Google Earth Pro; PNG 1:100,000 Port Moresby Topographic Map).

the southern end of Caution Bay and is particularly prominent in the vicinity of the Vaihua River estuary, where it extends up to 1.5km inland (Figure 7.2).

The barrier reef forms the southern boundary of Caution Bay, beyond which the sea floor drops away rapidly to depths exceeding 1,000m (Figure 7.1). Between the two reef complexes, water depths average 25m and reach a maximum of 50m, although there are many isolated coral bommies rising to depths up to 5m below sea level, especially in the southern part of the bay. The barrier reef at Caution Bay forms part of the extensive Papuan Barrier Reef that runs more or less continuously along the south coast of Papua New Guinea (PNG) from Yule Island, approximately 80km to the northwest of Caution Bay, down to the tip of the Southeast Papuan Peninsula at Milne Bay (Huber 1994). This barrier reef provides effective protection for the coastline from ocean swells.

Idihi Island is a coral cay surrounded by the outer barrier reef, located 15km southwest of the Vaihua River mouth. By sea, access in and out of Caution Bay is via natural openings in the barrier reef to the north of Idihi Island and to the south via Liljeblad Passage, a narrow natural

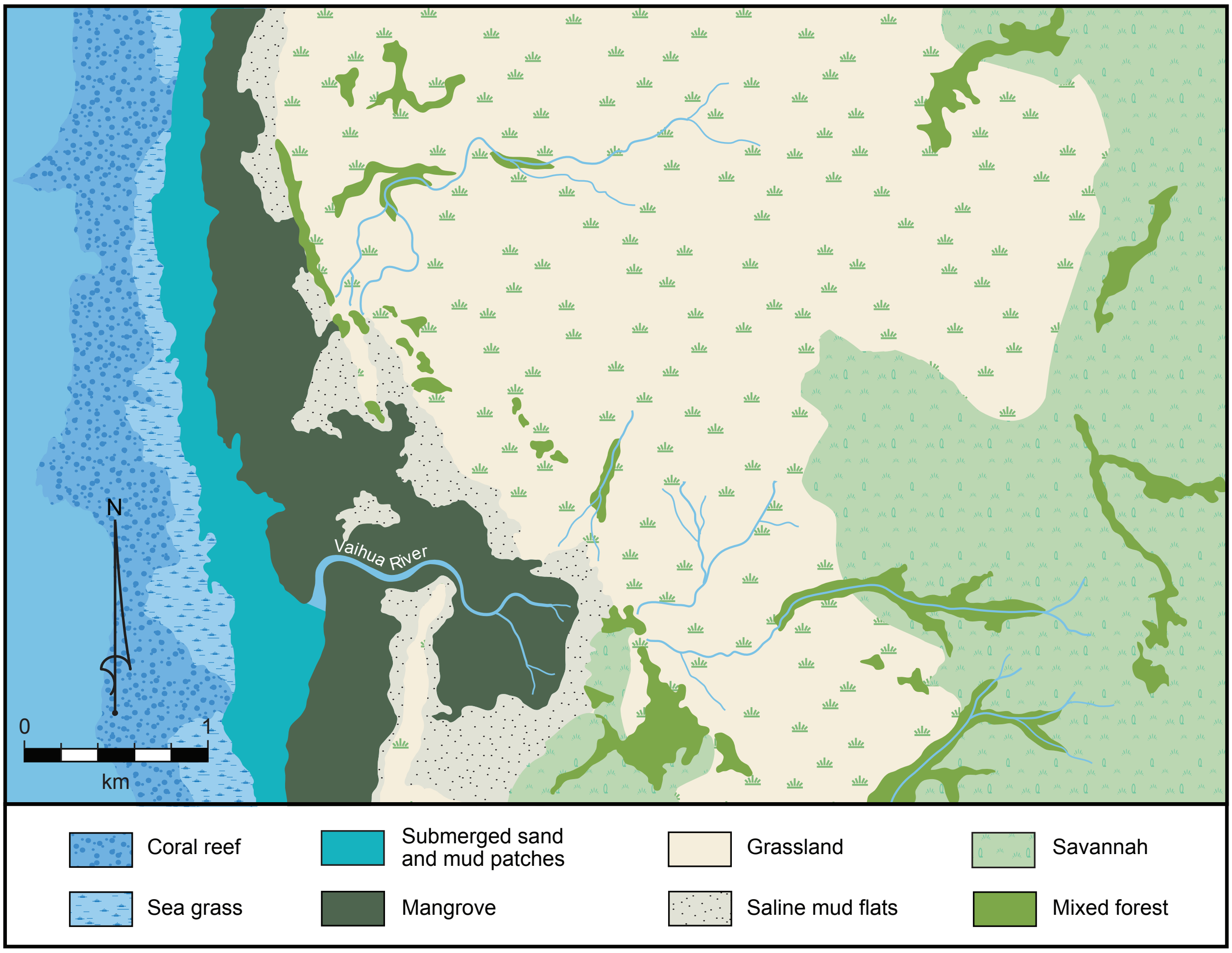

FIGURE 7.2. MARINE AND TERRESTRIAL HABITATS OF THE CAUTION BAY STUDY AREA (SOURCE INFORMATION INCLUDES: PNG 1:100,000 PORT MORESBY TOPOGRAPHIC MAP; GOOGLE EARTH PRO; WOXVOLD 2008: FIGURES 5 AND 9).

break in the barrier reef that lies offshore of the villages of Boera and Porebada (Figure 7.1).

Sources of Information

A major source of information on the Caution Bay environment is Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Land Research and Regional Survey study of the Port Moresby-Kairuku area, undertaken in 1962 (Mabbutt *et al.* 1965). Caution Bay is centrally located within the Port Moresby-Kairuku study area, and the integrated 'land systems' approach employed by the CSIRO provides a wealth of information on the regional climate, geology, geomorphology, soils, and vegetation, as well as some information on historical and contemporary patterns of land use. However, the survey did not extend to the terrestrial fauna, nor did it include any characterization of freshwater aquatic or marine ecosystems.

More recent information on all components of the regional environment was collected as part of the environmental impact assessments for the then-planned liquefied natural gas plant at the southern end of Caution Bay (CNS 2008a, 2008b, 2009; Hydrobiology 2008; Woxvold 2008). A major conclusion of the marine study was that the near-shore and reef environments of Caution Bay have been heavily degraded in recent times (CNS 2008a). Accordingly, to gain a sense of how these environments might have looked in the past, even for a mere 50 or so years ago, we must rely on information gleaned more widely from along the southern coast of mainland PNG, especially in areas where recent human impacts have been less pronounced than at Caution Bay and, more generally, than in the Port Moresby region. A useful summary of traditional and recent patterns of human exploitation of marine resources in this area is provided by Pernetta and Hill (1981; see also Swadling 1977b, 1994).

The terrestrial fauna of the Caution Bay area has also been impacted by historic to modern land use practices (Woxvold 2008). For the vertebrate fauna we can draw certain inferences from historical collections made in the wider Port Moresby region, which was a focus for the earliest biological exploration of the southern half of PNG, the Territory of Papua (Frodin and Gressitt 1982). Woxvold (2008: appendices 1 and 2) lists the vertebrates that are either known to occur in the hinterland of Caution Bay or are likely to have occurred there in recent times, based on the distributional summaries provided by Flannery (1995a) for mammals – see also Bonaccorso (1998) for bats; Beehler *et al.* (1986), Bell (1982), Coates (1985, 1990) and Mackay (1970) for birds; O'Shea (1996) for snakes; Georges and Thomson (2010) for turtles; and Menzies (2006) for frogs.

The extant molluscan fauna of Caution Bay has not been investigated at any stage. For this taxonomic group we compiled a species list based on our ongoing analysis of molluscan assemblages from excavated archaeological sites in the Caution Bay study area, including Bogi 1, Tanamu 1, 2 and 3, Edubu 1, Ataga 1, and Nese 1. Since most of the species represented in these sites are widely distributed in the Indo-Pacific region, their habitat preferences and behaviours are generally well known from studies elsewhere. Figure 7.3 shows the habitat associations of the molluscan taxa found in archaeological contexts at Caution Bay. Additional relevant information for the most common taxa recorded in the sites is provided in the descriptions of each of the major habitats.

Additional primary sources on the Caution Bay environment are Pain and Swadling's (1980) study of the geomorphological origin of the coastal plain and Rowe

Figure 7.3. Molluscan taxa from excavated archaeological sites in the Caution Bay study area, with a summary of their likely occurrence across the various marine to freshwater habitats. Habitat information has been predominantly drawn from Poutiers' comprehensive chapters on bivalves and gastropods of the Western Central Pacific found in the FAO Species Identification Guide prepared by Carpenter and Niem (1998). Additional supplementary resources were referred to when we encountered species in the archaeological assemblages that were not present in this guide. These include Baron and Clavier (1992), Bellchambers et al. (2011), Coleman (2003), Houbrick (1987), Lamprell and Healy (1998), Malaquias and Reid (2008), Poiner and Catterall (1988) and Tebano and Paulay (2000). The online World Register of Marine Species was also consulted in each instance (WoRMS Editorial Board 2014).

Family	Taxon	Common Name	Estuaries, Mangroves and Upper Tidal Mud Flats			Intertidal Sand-Mud Flats	Shallow Sandy Seafloor and Seagrass Beds	Intertidal Rocky Shores	Coral Reef Flats	Freshwater Environments
			Mangrove Roots	Mangrove and Estuarine Muds	Tidal Mud Flats					
Bivalvia										
Arcidae	*Anadara antiquata* (Linnaeus, 1758)	Antique ark				X	X			
Arcidae	*Anadara* spp. (Gray, 1847)	Ark		X	X	X	X			
Arcidae	*Barbatia foliata* (Forsskål, 1775)	Decussate ark						X		
Arcidae	*Tegillarca granosa* (Linnaeus, 1758)	Granular ark		X	X					
Mytilidae	Mytilidae (Rafinesque, 1815)	Sea mussels						X		
Pinnidae	Pinnidae (Leach, 1819)	Pen shells			X				X	
Pteriidae	*Pinctada* spp. (Röding, 1798)	Pearl oysters						X		
Isognomonidae	*Isognomon* spp. (Lightfoot, 1786)	Tree oysters	X					X		
Malleidae	*Malleus* spp. (Lamarck, 1799)	Hammer oysters			X			X	X	
Pectinidae	*Decatopecten radula* (Linnaeus, 1758)	Flatribbed scallop				X		X	X	
Pectinidae	*Mimachlamys sanguinea* (Linneaus, 1758)	Common scallop			X	X		X		
Spondylidae	*Spondylus* spp. (Linnaeus, 1758)	Thorny oysters						X	X	

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			Mangrove Roots	Mangrove and Estuarine Muds	Tidal Mud Flats					
Placunidae	*Placuna ephippium* (Philipsson, 1788)	Saddle oyster	X	X	X					
Placunidae	*Placuna placenta* (Linnaeus, 1758)	Windowpane oyster	X	X	X					
Ostreidae	Ostreidae (Rafinesque, 1815)	Oysters	X					X		
Lucinidae	*Anodontia edentula* (Linnaeus, 1758)	Toothless lucine	X	X						
Lucinidae	*Austriella corrugata* (Deshayes, 1843)	Corrugate lucine	X	X						
Chamidae	*Chama* spp. (Linneaus, 1758)	Jewel box shells						X	X	
Carditidae	*Beguina semorbiculata* (Linnaeus, 1758)	Halfround cardita						X		
Cardiidae	*Fragum unedo* (Linnaeus, 1758)	Pacific strawberry cockle				X				
Tridacnidae	*Hippopus hippopus* (Linnaeus, 1758)	Bear paw clam							X	
Tridacnidae	*Tridacna* spp. (Bruguière, 1797)	Giant clam							X	
Mactridae	*Mactra* spp. (Linneaus, 1758)	Trough shells			X	X				
Mesodesmatidae	*Atactodea striata* (Gmelin, 1791)	Striate beach clam				X				
Tellinidae	*Tellina palatum* (Iredale, 1929)	Palate tellin				X				
Tellinidae	*Tellina remies* (Linnaeus, 1758)	Remies tellin			X	X				
Tellinidae	*Tellina* spp. (Linnaeus, 1758)	Tellins				X				
Tellinidae	*Tellina staurella* (Lamarck, 1818)	Cross tellin				X				
Psammobiidae	*Asaphis violascens* (Forsskål, 1775)	Pacific asaphis				X				
Psammobiidae	*Gari occidens* (Gmelin, 1791)	Sunset shell		X	X					
Cyrenidae	*Batissa violacea* (Lamarck, 1806)	Violet batissa			X					X
Cyrenidae	*Geloina) erosa* (Lightfoot, 1786)	Common geloina		X						
Corbulidae	*Corbula fortisulcata* (Smith, 1879)	Basket shell			X	X				
Modulidae	*Modulus tectum* (Gmelin, 1791)	Knobby snail			X	X				
Semelidae	*Semele cordiformis* (Holten, 1802)	Semele shell			X					
Veneridae	*Anomalodiscus squamosus* (Linnaeus, 1758)	Squamose venus				X				
Veneridae	*Gafrarium tumidum* (Röding, 1798)	Tumid venus				X				
Veneridae	*Gafrarium pectinatum* (Linnaeus, 1758)	Comb venus				X				
Veneridae	*Periglypta puerpera* (Linneaus, 1771)	Princess venus clam			X	X				
Veneridae	*Pitar pellucidus* (Lamarck, 1818)	Pellucid pitar venus				X				
Veneridae	*Prototapes gallus* (Gmelin, 1791)	Rooster venus				X				
Veneridae	*Tapes literatus* (Linnaeus, 1758)	Lettered venus				X				
Gastropoda										
Angariidae	*Angaria delphinus* (Linnaeus, 1758)	Common delphinula						X	X	

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			Mangrove Roots	Mangrove and Estuarine Muds	Tidal Mud Flats					
Bullidae	*Bulla ampulla* (Linneaus, 1758)	Bubble shell					X			
Calliostomatidae	*Calliostoma* spp. (Swainson, 1840)	Calliostoma top snails						X		
Chilodontidae	*Euchelus atratus* (Gmelin, 1791)	Blackish margarite				X		X		
Fasciolariidae	*Benimakia fastigium* (Reeve, 1847)	Red mouthed latirus			X	X		X		
Fissurellidae	*Hemitoma* spp. (Swainson, 1840)	Slit limpets						X		
Liotiidae	*Liotina peronii* (Kiener, 1839)	Peron's delphinula						X		
Trochidae	*Monodontia labio* (Linnaeus, 1758)	Labio monodont						X	X	
Trochidae	*Tectus fenestratus* (Gmelin, 1791)	Fenestrate top						X		
Trochidae	*Tectus niloticus* (Linnaeus, 1767)	Commercial top							X	
Trochidae	Trochidae (Rafinesque, 1815)	Top shells						X	X	
Trochidae	*Trochus maculatus* (Linnaeus, 1758)	Maculated top						X	X	
Trochidae	*Trochus nigropunctatus* (Reeve, 1861)	Black-spotted top						X	X	
Trochidae	*Trochus* spp. (Linnaeus, 1758)	Top shells						X		
Turbinidae	*Turbo argyrostomus* (Linnaeus, 1758)	Silvermouth turban							X	
Turbinidae	*Lunella cinerea* (Born, 1778)	Smooth moon turban						X		
Turbinidae	*Turbo crassus* (Wood, 1828)	Crass turban							X	
Neritidae	*Nerita albicilla* (Linnaeus, 1758)	Oxpalate nerite						X		
Neritidae	*Nerita balteata* (Reeve, 1855)	Black nerite		X				X		
Neritidae	*Nerita chameleon* (Linnaeus, 1758)	Chameleon nerite						X		
Neritidae	*Nerita planospira* (Anton, 1839)	Flat-spired nerite		X				X		
Neritidae	*Nerita* spp. (Linneaus, 1758)	Nerites		X				X		
Neritidae	*Theodoxus fluviatilis* (Linneaus, 1758)	River nerite								X
Littorinidae	*Littoraria filosa* (Sowerby, 1832)	Periwinkle	X							
Littorinidae	*Littoraria scabra* (Linnaeus, 1758)	Rough periwinkle	X							
Cerithiidae	Cerithiidae (Fleming, 1822)	Ceriths		X		X				
Cerithiidae	*Cerithium citrinum* (Sowerby, 1855)	Cerith					X		X	
Cerithiidae	*Cerithium coralium* (Kiener, 1841)	Coral cerith		X						
Cerithiidae	*Cerithium zonatum* (Wood, 1828)	Cerith							X	
Cerithiidae	*Clypeomorus batillariaeformis* (Habe and Kosuge, 1966)	Necklace cerith				X			X	
Planaxidae	*Planaxis sulcatus* (Born, 1778)	Furrowed clusterwinkle						X		
Potamididae	*Cerithidea cingulata* (Gmelin, 1791)	Girdled horn shell		X						

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			Mangrove Roots	Mangrove and Estuarine Muds	Tidal Mud Flats					
Potamididae	*Cerithidea largillierti* (Philippi, 1848)	Horn snail		X						
Potamididae	*Telescopium telescopium* (Linnaeus, 1758)	Telescope snail		X						
Potamididae	*Terebralia sulcata* (Born, 1778)	Sulcate swamp cerith	X	X						
Turritellidae	Turritellidae (Loven, 1847)	Turret shells			X	X				
Strombidae	*Canarium labiatum* (Linnaeus, 1758)	Plicate conch				X	X			
Strombidae	*Canarium urceus* (Linnaeus, 1758)	Little pitcher conch				X				
Strombidae	*Conomurex luhuanus* (Linnaeus, 1758)	Strawberry conch				X	X		X	
Strombidae	*Euprotomus aurisdianae* (Linnaeus, 1767)	Diana conch				X	X		X	
Strombidae	*Gibberulus gibberulus* (Linnaeus, 1758)	Gibbose conch				X	X		X	
Strombidae	*Laevistrombus canarium* (Linnaeus, 1758)	Dog conch			X		X		X	
Strombidae	*Lambis crocata* (Link, 1807)	Orange spider conch							X	
Strombidae	*Lambis lambis* (Linnaeus, 1758)	Common spider conch		X	X				X	
Strombidae	*Lambis scorpius* (Linnaeus, 1758)	Scorpio spider conch						X	X	
Strombidae	*Lambis* spp. (Röding, 1798)	Spider conch		X					X	
Cypraeidae	Cypraeidae (Rafinesque, 1815)	Cowrie shells						X	X	
Cypraeidae	*Mauritia arabica* (Linnaeus, 1758)	Arabian cowrie						X	X	
Cypraeidae	*Monetaria annulus* (Linnaeus, 1758)	God ring cowrie				X				
Naticidae	Naticidae (Guilding, 1834)	Moon shells				X				
Naticidae	*Mammilla sebae* (Recluz, 1844)	Seba's moon snail				X				
Naticidae	*Natica stellata* (Hedley, 1913)	Starry moon snail		X	X	X				
Naticidae	*Notocochlis gualteriana* (Recluz, 1844)	Gualteri's moon snail		X	X	X				
Naticidae	*Polinices mammilla* (Linnaeus, 1758)	Pear-shaped moon snail				X			X	
Naticidae	*Polinices peselephanti* (Link, 1807)	Elephant's-foot moon snail				X				
Tonnidae	*Tonna* sp. (Brünnich, 1771)	Tun shell					X			
Ranellidae	*Cymatium* sp. (Röding, 1798)	Triton shell				X		X		
Muricidae	*Chicoreus capucinus* (Lamarck, 1822)	Mangrove murex	X	X						
Muricidae	*Chicoreus* sp. (Montfort, 1810)	Murex shell			X			X	X	
Muricidae	*Cronia aurantiaca* (Hombron and Jacquinot, 1848)	Golden rock shell			X			X		
Muricidae	*Drupella margariticola* (Broderip, 1833)	Shouldered castor bean						X		

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Muricidae	*Morula uva* (Röding, 1798)	Grape drupe						X	X	
Muricidae	*Thais* sp. (Röding, 1798)	Rock shell						X		
Buccinidae	*Cantharus* spp. (Röding, 1798)	Whelks						X		
Columbellidae	*Mitrella scripta* (Linnaeus, 1758)	Dotted dove shell						X	X	
Nassariidae	*Nassarius* spp. (Dumeril, 1805)	Dog whelk mud snails				X				
Nassariidae	*Nassarius crematus* (Hinds, 1844)	Burned dog whelk				X				
Nassariidae	*Nassarius distortus* (Adams, 1852)	Distorted dog whelk				X				
Nassariidae	*Nassarius olivaceus* (Bruguière, 1789)	Olivaceus dog whelk				X				
Nassariidae	*Nassarius pullus* (Linnaeus, 1758)	Black dog whelk				X				
Turbinelliidae	*Vasum turbinellus* (Linnaeus, 1758)	Top vase						X	X	
Olividae	*Oliva* spp. (Bruguière, 1789)	Olive shells				X				
Mitridae	*Cancilla* sp. (Swainson, 1840)	Miter shell				X				
Mitridae	*Mitra* sp. (Lamarck, 1798)	Miter shell						X		
Costellariidae	*Vexillum rugosum* (Gmelin, 1791)	Rugose miter				X				
Costellariidae	*Vexillum vulpecula* (Linnaeus, 1758)	Little-fox miter				X				
Conidae	*Conus arenatus* (Hwass, 1792)	Sand-dusted cone				X			X	
Conidae	*Conus flavidus* (Lamarck, 1810)	Yellow Pacific cone						X	X	
Conidae	*Conus lividus* (Hwass, 1792)	Livid cone						X	X	
Conidae	*Conus* spp. (Linnaeus, 1758)	Cone shells				X		X	X	
Conidae	*Conus striatus* (Linnaeus, 1758)	Striated cone				X			X	
Conidae	*Conus textile* (Linnaeus, 1758)	Textile cone				X		X	X	
Turridae	*Lophiotoma indica* (Röding, 1798)	Indian turrid			X					
Terebridae	*Duplicaria duplicata* (Linnaeus, 1758)	Duplicate auger shell				X			X	
Terebridae	Terebridae (Mörch, 1852)	Auger shells			X	X			X	
Dolabellidae	*Dolabella auricularia* (Lightfoot, 1786)	Sea cats					X			
Ellobiidae	*Cassidula* sp. (Gray, 1847)	Mangrove ear snail	X	X						
Ellobiidae	*Ellobium aurisjudae* (Linnaeus, 1758)	Judas ear cassidula	X	X						
Ellobiidae	*Ellobiidae* (Pfeiffer, 1854)	Hollow-shelled snails	X							
Ellobiidae	*Melampus luteus* (Quoy & Gaimard, 1832)	Yellow melampus		X						

et al.'s (2013) study of Holocene vegetation history from palynological records, the latter undertaken by the Caution Bay Archaeology Project.

Finally, extensive use has been made of Google Earth satellite imagery which is especially helpful in a locality such as Caution Bay, where topographic mapping accuracy is uneven. The satellite images were employed to determine the presence and extent of natural features including coral reefs, sandy beaches, mudflats, grasslands, savannah, watercourses, etc., as well as man made features such as villages and gardens.

Terminology of Environmental Zones and Habitats

Four broad-scale landscape components make up the present-day physical environment of Caution Bay and its environs, namely the: 1) littoral plains zone; 2) hinterland zone; 3) inshore marine zone; and 4) offshore marine zone.

The aforementioned 'land systems' report (Mabbutt *et al.* 1965) contains a comprehensive classification of regional terrestrial landscape components, based on a combination of physiographic, geomorphic and biotic parameters, and created a hierarchical nomenclature of 'zones' and 'land systems' within zones. We have adopted the 'zone' terminology of Mabbutt *et al.* (1965) and used it throughout this chapter. However, because the 'land system' nomenclature is based on 'typical' localities (e.g., 'Waigani Land System') that fall outside of Caution Bay, and which bear names that provide no clues as to the associated plant and animal resources, we have elected not to follow this terminology. Instead we have developed a slightly broader set of categories that are descriptors of the natural environment, and where possible and relevant, we cross-reference our categories with the Mabbutt *et al.* (1965) land systems.

Climate

The nearest long-term climate data to Caution Bay come from Port Moresby located only 20km to the southeast (BoM 2015a). The two areas are sufficiently similar in topography and biotic environments to regard these records as representative for the study area. Figure 7.4 shows averaged monthly trends for a number of important climate parameters, based on measurements taken over the past 40 years at Jackson Airport, Port Moresby.

The climate of the Port Moresby-Caution Bay region is classified as Tropical Savanna (Köppen code Aw; henceforth 'savannah') under the international Köppen-Geiger system (Peel *et al.* 2007). Tropical Savanna is defined by a combination of elevated year-round temperatures and a high annual rainfall with pronounced seasonality. Across New Guinea only a few, relatively small areas of the lowlands meet these criteria; the dominant climate regime for the island is Tropical Rainforest (Köppen code Af; Peel *et al.* 2007).

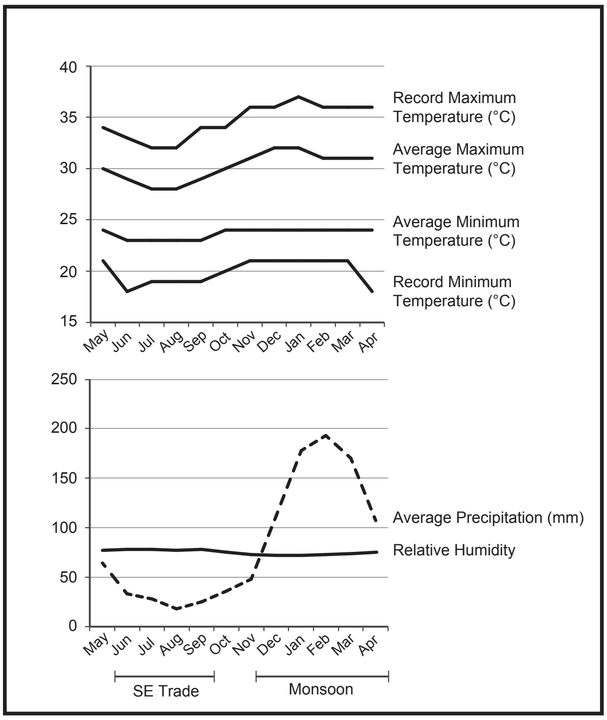

Figure 7.4. Averaged monthly trends for important climate parameters, based on measurements taken over the past 40 years at Jackson Airport, Port Moresby (based on data from BoM 2015a).

Daily mean minima and maxima air temperatures at Port Moresby attain peak monthly averages of 24°C and 32°C respectively in the months of December and January, and low monthly averages of 23°C and 28°C respectively in the months of July and August (BBC 2006). The recorded daytime minima and maxima across the full 40 years is 18°C to 36°C. Daily temperature maxima are usually slightly higher away from the coast due to the ameliorating effects of sea breezes (see below). Further inland, daily temperatures remain high until significant elevation is reached in the foothills of the Owen Stanley Range. Overnight temperature minima fall with distance from the coast, and continue to fall with increasing elevation.

Average annual rainfall measured at Port Moresby is 1,012mm, making it one of the driest localities in PNG. Rainfall events are exceptionally low through the period June to October, with average monthly totals of 18mm to 36mm. A distinct wet season is experienced from December to April when average monthly rainfalls are between 112mm and 193mm. Over the full 40 years of records, February stands out as the wettest month (BBC 2006).

Relative humidity shows a narrow range of variation, with monthly averages of 72% to 78% for morning readings and 69% to 78% for afternoon readings. Slightly higher humidity is observed during the winter months of May to August.

Winds during the summer months are generally less than 31km/hour (17 knots), with stronger winds occurring only 15% of the time. Windier conditions prevail during the winter, in association with southeast Trade winds (see below), with winds exceeding 31km/hour for 30% of the time.

Annual evaporation ranges between 1,900mm to 2,400mm for the dry coastal-lowlands of southern PNG (McAlpine *et al.* 1983), with average monthly evaporation peaking at 210mm in November and falling to a low of 145mm in June. As rainfall during the June to October period clearly falls well below effective evaporation in the Port Moresby-Caution Bay region, there are significant periods of negative regional water balance each year. McAlpine *et al.* (1983) provide further information on this seasonal water deficit and its effects.

The seasonal climatic pattern of southern PNG is under predominant control of two regional weather systems – a 'monsoonal' system that operates during December to April and produces the (austral) summer 'wet' season; and the southeast Trade wind system which blows from June to October and produces a contrasting winter 'dry' season (McAlpine *et al.* 1983; Sturman and Tapper 2001). Short periods of more changeable weather, sometimes called the 'doldrums', occur during the transitional months of May and November (Prentice and Hope 2006; Sturman and Tapper 2001).

The monsoon season in southern New Guinea can commence any time from late November to mid-January, although the most likely time of onset is late December. Variation in the time of onset probably has multiple causes. El Niño-Southern Oscillation (ENSO) phases tend to be preceded by an early-onset monsoon followed by a later-onset monsoon. A delayed-onset of the monsoon in southern New Guinea has also been linked to a weak Indian monsoon, while the reverse also seems to be true.

Rainfall during the monsoon season is typically episodic, with alternating episodes of 'burst' (wet) and inactivity or 'break' (dry) conditions. 'Break' conditions typically account for around 20% of the monsoon season (McAlpine *et al.* 1983; Sturman and Tapper 2001). Sturman and Tapper (2001) identify a possible 40-50 day oscillation in the 'burst and break' cycle, and discuss the underlying climatic mechanisms.

The monsoon season in southern New Guinea is also the cyclone season. However, most tropical cyclones originate to the east of Port Moresby, further down the Papuan Peninsula, and their impact in Port Moresby and Caution Bay is usually limited to episodes of intense windiness and heavy rainfall. Only three cyclones have tracked within 100km of Caution Bay in the last 40 years (1970-2010) (BoM 2015b).

Local weather conditions in the Port Moresby-Caution Bay region are also determined by the interplay of land and sea surface temperatures. McAlpine *et al.* (1983) describe how 'sea breeze cells' form just offshore during the morning and expand both landward and seaward as the day progresses. Movement of the landward frontal zone across the coastline is accompanied by local wind gusts, rain showers, and falling temperatures and humidity. In addition, convective clouds may develop along the frontal zone, reaching thunderstorm stage by the time the front reaches the inland ranges. After sunset the sea breeze cell diminishes and dies, to be replaced on occasion by a 'land breeze cell' that creates offshore winds (Fitzpatrick 1965; McAlpine *et al.* 1983). Regular sea breezes in the Port Moresby-Caution Bay region ensure that daily temperature maxima are usually lower close to the coast than further inland on the coastal plain (Fitzpatrick 1965; Löffler 1982).

Topographic factors also play a role in determining local weather patterns at various scales along southern PNG. At a broad scale, the complex amalgam of mountain ranges that make up the Central Cordillera of New Guinea induces heavy orographic rainfall throughout much of the year. The forested ranges also produce their own local climate systems. A daily cycle of heating and cooling of air masses within steep-sided valleys creates convection cells that produce afternoon and overnight rainfalls throughout the year, but at variable intensities depending on the moisture content of regional air masses (Löffler 1982; Whittow 2000). The Owen Stanley Range that forms the backdrop to Caution Bay thus has a climate that, while still seasonal, is not subject to the dry season moisture deficit that characterizes the adjacent coast.

At a regional scale, the alignment of mountain ranges and valleys relative to prevailing winds has a significant impact on rainfall patterns. For the Port Moresby-Caution Bay region, the unusually low annual rainfall is likely due in part to the generally parallel alignment of the coast and ranges with both the monsoonal and Trade winds. By contrast, areas to the east and northwest have the coast and ranges set obliquely to the prevailing winds. This creates a more effective funnelling and uplift of moisture-laden air, resulting in correspondingly higher rainfall (Fitzpatrick 1965; Löffler 1982; McAlpine *et al.* 1983).

At a local scale, the topographic relief of a few hundred meters across the lowland plain is sufficient to produce slight variations in rainfall and temperature, with implications for natural biotic communities and human activity (Fitzpatrick 1965; McAlpine *et al.* 1983). Contributing factors include the rain-shadow effects of hills and ridges, the daily cycle of local air and moisture movement along valleys and across adjacent plains in response to differential rates of heating and cooling, and the variable frictional properties of different landforms and plant communities that create contrasting patterns of wind-shear and turbulence, with impacts on rainfall frequency and intensity.

Inter-annual climatic variability in southern New Guinea is strongly influenced by ENSO cycles (Hastenrath 2012; Prentice and Hope 2006). El Niño and La Niña events typically begin to develop in May or June and last for just under one year (Allen and Bourke 2009). La Niña events bring increased rainfall that can lead to flooding and slope instability, while El Niño events typically involve prolonged droughts. In Port Moresby-Caution Bay, El Niño events create cooler dry and wet seasons than normal, and lower seasonal sea level and tidal reach. In contrast, during La Niña events only the dry season is warmer and both seasonal sea level and tidal reach are significantly higher (BoM 2015a). Tropical cyclones are more frequent in southeastern New Guinea in ENSO-neutral years (eight cyclones per decade) and less so under El Niño and La Niña (four cyclones per decade) (BoM 2015a).

Minor ENSO events typically occur around every five to six years, with more pronounced events every 12 years on average (BoM 2015a). Particularly severe ENSO events with widespread consequences across PNG occurred in the years centring on 1902, 1914, 1941 and 1997 (Allen and Bourke 2009; Sturman and Tapper 2001).

Environmental Zones and their Resources

The Littoral Plains Zone

The Littoral Plains Zone was a clear focus of local human activity from the mid-Holocene into recent times, as shown especially by the Caution Bay archaeological results. It is thus an appropriate place to begin our description of the Caution Bay landscape.

Littoral Plains Zone Landforms

The Littoral Plains Zone is 0.4km to 1.75km wide along the Caution Bay study area coastline and contains a variety of landforms including sandy beaches, barrier dunes, sand spits, beach ridges, estuarine mouths, and a differentiated complex of tidal mudflats (outer tidal, lower inner and higher inner flats) that differ in inundation depth and frequency. The landforms of the Littoral Plains Zone were created by the interplay of littoral, fluvial and aeolian processes, and are indicative of an accreting (i.e., growing or extending) coastal plain. For the most part, these landforms appear to date to the most recent marine transgression, i.e., the mid- to late Holocene (Pain and Swadling 1980). The sandy beach and barrier/spit/beach ridge complexes correspond with the Hisiu land system of Mabbutt *et al.* (1965), while the tidal flats are representative of their Papa land system.

Narrow sandy beaches are present along much of the Caution Bay coastline that does not support a fringing mangrove community, but there is presently only one small beach in the study area, at Konekaru where there is a small break in the mangrove barrier (Figure 5.6). Beach sediments are medium to fine sands mixed in variable proportion with triturated coral and shell. The beach-fronts are low-angled and relatively stable, reflecting the generally low wave action of the protected environment of the coastal lagoon. Beach drift varies seasonally according to the direction of the prevailing on-shore winds that create local wave trains; beach drift is predominantly easterly or southeasterly under the influence of the stronger winter winds.

Sandy beaches at Caution Bay typically merge landwards to low barrier systems of foredunes and/or beach ridges. These landforms are usually best defined near the present shore-line and become more subdued inland. According to Mabbutt (1965), the dunes and ridges were initially produced by the combination of wave and wind action, while secondary modification by the prevailing southeasterly winds account for the subdued forms of older dunes and ridges inland. The beach ridge habitat attains a maximum width of 1.5km.

Beach ridges (or sand spits) are most prominently developed around the Vaihua River inlet. In this area three ridge systems are present, together with small remnants, all lying along approximately the same line (Pain and Swadling 1980). As noted above, the ridges and remnants show different stages of soil development and may signal prior high sea level episodes dating to the Quaternary. A prominent beach ridge feature of mid to late Holocene age runs north of the Vaihua River inlet, paralleling the coast along a length of ~ 2km, with a crest ~ 4-5m above the high tide mark. Many key excavated archaeological sites, including Bogi 1 and Tanamu 1, are located on this ridge (David *et al.* 2011; McNiven *et al.* 2011).

Rowe *et al.* (2013) reported additional low beach ridges within the belt of fringing mangrove vegetation a short distance to the west of Bogi 1. These are representative of episodes of slightly higher sea level during the late Holocene, when seaward growth of the mudflats was briefly interrupted by the formation of more continuous sandy beaches under a regime of reduced protection from a submerged offshore reef.

Mudflats are present along relatively well-protected sections of the coastline and in the various estuaries. Such mudflats occur at a number of distinct tide levels, including subtidal, tidal (incorporating outer tidal and inner tidal) and supratidal, each more elevated than the last. Each of these categories has a characteristic inundation depth and frequency, a contrasting sedimentology, and typical biotic communities (both plants and animals; see below). The supra-tidal mudflats represent the extreme upper limit of tidal reach (Mabbutt 1965; Pain and Swadling 1980). Drainage of the various tidal and supra-tidal mudflats is by a network of small creeks and lagoons with transient flow.

The main occurrences of supra-tidal mudflats are behind the protective barrier complex of dunes and sand spits, and around the Vaihua River estuary. These surfaces are flat to very gently sloping. Here surface sediments are predominantly clays and muds. In places tidal scour has removed finer materials, creating localized sandy patches. Finer sandy materials are also present where sand spits are being eroded. Patches of coarser sand and gravel occur along the landward margin of the supra-tidal mudflats where ephemeral watercourses debouch from the hinterland area; examples include Ruisasi Creek in the centre of the study area and Moiapu, Dirora, Ebutodahana, Kiohedova and Edubu Creeks in the south (Figure 5.2).

The Vaihua River estuary is located in the southwest corner of the Caution Bay study area and represents the major landward incursion of mudflat landforms in the southern part of Caution Bay. Prior to development of the mudflats, the Vaihua River would have received direct, albeit intermittent, flow from each of Moiapu, Dirora, Ebutodahana, Kiohedova and Edubu Creeks. However, as noted above, each of these creeks now debouches onto the supra-tidal mudflat, and continuation of flow into the Vaihua River occurs via a series of ephemeral channels that link interconnected shallow basins, and through subsurface seepage.

Littoral Plains Zone Soils

The following characterizations are drawn from the general accounts of Scott (1965) and Mabbutt (1965), supplemented with information provided by Rowe *et al.* (2013) and observations made during the Caution Bay archaeological excavations.

Beach Soils

Scott (1965: 131) divided this soil group into three soil families based on colour and profile development, with systematic variations observed with distance inland:

1. *Grey fine sands* are typically well-sorted and, as a result of instability of the surface layer, show no obvious development of an A horizon. Grey fine sands occur on foredunes, and those developed on higher surfaces are especially well-drained. The profiles are alkaline throughout but can show mottling at depth.
2. *Brown fine sands* are similar in most respects to the grey sands, but stable enough to show weak development of an A horizon. They occur on inner beach ridges and sand plains. The A horizon is typically 20-30cm-thick and comprises black to dark brown, mildly granular to loose fine sands. This is underlain by dark greyish to olive brown fine sands lacking obvious structure. Alkalinity generally increases with depth but can be quite high even near the surface. Subsurface character is strongly influenced by relations with the water-table; poorly drained soils show strong mottling at depth and a greying in the vicinity of the water-table. Mobilization of carbonates within the soil profile, and the formation of a carbonate crust over clasts (especially but not exclusively of bone), was observed in a number of excavations carried out within the Littoral Plains Zone, including at the sites of Bogi 1 and Tanamu 1 (for general information on these sites, see David *et al.* 2011; McNiven *et al.* 2011).
3. *Grey sands* are loose sands found along the active beach margin. Grey sands usually contain significant but variable components of coarsely to finely triturated coral and shell. Fine fractions are often removed by wind action. Beach-front sediments of this kind were encountered at depth in a number of the archaeological excavations, especially those on the beach ridge north of the Vaihua River inlet. These typically showed a moderate to high degree of carbonate cementation and encrustation, especially of bone fragments.

Mudflat Soils

Scott (1965: 131-133) distinguished two soil groups occurring on this general landform: *mangrove soils* and *intertidal alluvial soils*. They differ primarily in their subsurface macro-organic contents.

Mangrove soils are characterized by a 30-100cm-thick layer of organic sandy clay to sand, overlying a mangrove peat layer. All mangrove soils are regularly inundated by tides and are thus poorly drained; the majority is subject to regular bioturbation by crabs (Mabbutt 1965; Scott 1965). Scott (1965: 132) distinguished three soil families in this group, distinguished by the sediment grade of surficial levels:

1. *Grey sandy peats* found on the outer tidal flats and subject to daily inundation and regular winnowing through wave action.

2. *Grey loamy peats* found on the inner tidal flats behind beach ridges; these are typically inundated to depths of 1m to 1.5m at high tide. Mabbutt (1965: 126) describes prominent crab-built mounds from mean sea level up to the high water mark; these were 'closely spaced platforms up to 4 ft high and 5 yd across, with a maze of interconnecting tidal leads'.
3. *Grey clayey peats* found on the innermost tidal or supra-tidal flats, where inundation is shallow and limited to very high tides.

Intertidal Alluvial Soils

Intertidal alluvial soils are subject to tidal and/or estuarine influence and are variably saline to neutral, the latter where under a dominant riverine influence. Scott (1965: 133) distinguished three soil families in this group:

1. *Grey to brown sticky clays* found on tidal mudflats subject to shallow inundation at very high tides. The soil is strongly alkaline throughout the profile.
2. *Brown sticky clays* found in pans or depressions, possibly marking the position of former lagoons. The upper soil profile is typically black to very dark grey-brown sandy to heavy clays, with a blocky structure and a propensity to deep surface cracking. The soil colour changes to grey at the water table. Deeper sediments are sometimes sand or sandy loams, representing buried littoral deposits. The profile is strongly alkaline. Inundation occurs infrequently either by very high tides or through freshwater runoff from the landward margins. This soil type is well represented at Caution Bay.
3. *Silty grey clays* found in estuarine tidal flats and back-plains. These soils differ from the previous families in being neutral throughout, suggesting a stronger alluvial contribution and a lack of regular tidal inundation. At Caution Bay this soil family is also well represented in the Hinterland Zone (see below).

Rowe *et al.* (2013) described three sediment cores taken on the outer tidal, inner tidal and supra-tidal mudflats along a transect just north of the Vaihua River inlet; the first two cores were taken in current mangrove communities, while the third was taken on a bare supra-tidal mudflat. All three cores encountered a basal unit of pale, inorganic, gritty (shell and stone) consolidated clays. This was reached at the greatest depth (180cm) in the outer tidal core, and at shallowest depth (148cm) in the supra-tidal core. In the outer tidal core, a basal unit (180-105cm depth) of pale grey clay with significant shell fragments and sand but lacking fibrous organics or root materials was overlain by very dark brown organic clay with patchy fibrous and mud-like texture, and containing fine root material and occasional complete molluscan shells. In the supra-tidal core most of the profile (148-14cm depth) was dark, coarse organic clay with unidentifiable organic remains, fine root material and some fragmented shell and sandy fraction. The upper 14cm was mottled fine grey clay with localized red-brown colour but no sand, shell fragments or visible plant material.

Littoral Plains Zone Plant Communities

Vegetation communities show strong differentiation across the Littoral Plains Zone and there is a close association with landforms and depositional units (Heyligers 1965; Rowe *et al.* 2013):

1. A dense groundcover of *Spinifex-Canavalia* growing as a pioneer community on beach foredunes.
2. A dense coastal belt of tall (up to 10m height) mangrove forest dominated by *Rhizophora stylosa* (this community is also present in other low-lying areas subject to deep inundation).
3. A lower, more open mangrove forest dominated by *Avicennia marina* and growing in areas of shallower inundation, usually landward of the *Rhizophora* belt.
4. Dense scrub and thickets growing on the barrier dune and beach ridge landforms. Thickets differ from scrub through the presence of an open tree canopy above the scrub layer. Naturally occurring scrub and thicket typically occur in contexts unsuited to forest growth, and both vegetation types can incorporate evergreen and deciduous plant types (Brock 2001; Heyligers 1965). However, they can also represent an early stage of forest regeneration after fire or clearing.
5. Saltmarsh-like vegetation and grassland that occurs around the margins of otherwise bare saline mudflats or on low rises within these areas.
6. Herbfields and grasslands which grow on beach ridges and littoral sand plains.

The following more detailed accounts of plant communities derive from the descriptions of Heyligers (1965) and Rowe *et al.* (2013).

Spinifex-Canavalia Dune Vegetation

At maximum development this pioneer community forms a dense mat of sand-binding grasses (*Spinifex, Thuarea, Remirea,* with minor *Sporobolus, Digitaria, Apluda, Setaria,* and *Imperata*), with interwoven creeping herbs (*Ipomoea, Canavalia, Cassytha,* and *Passiflora*) and scattered emergent *Crotalaria*. At Caution Bay this association of taxa is found on several beaches above high water mark and on low foredunes. On more mobile beach-fronts only a few plant taxa may be present.

According to Paijmans (1976), herbs and creepers tend to be more effective colonists of seaward dune and/or beach-ridge slopes, while grasses and sedges are more likely to dominate on dune crests.

Rhizophora-Bruguiera Mangrove Forest

This forest type occupies areas subject to the most frequent and deepest tidal inundation. These areas of prolonged inundation include the seaward fringe and the mouth of the Vaihua River inlet. Areas of recent establishment have dense, even-aged and single-tiered stands of *Rhizophora*. Mixed forests of *Rhizophora-Bruguiera* represent a more mature community. Away from the margin, the forest becomes more complex in structure through the addition of *Camptostemon*, *Heritiera* and *Xylocarpusi* at canopy level and *Aegiceras, Brownlowia, Dolichandrone, Myristica*, palms and pandans as a multi-tiered understorey. Particularly open patches may have dense understoreys of pandans and tall sedges.

In most places, the boundary between the *Rhizophora-Bruguiera* and *Avicennia-Ceriops* mangrove forests is sharp as it corresponds with different aged and height sedimentary units within the overall mudflats landform. However, along the estuarine margin the *Rhizophora-Bruguiera* community grades into *Avicennia-Ceriops* mangrove forest along the salinity gradient, due to freshwater intolerance on the part of *Rhizophora* and *Bruguiera* (Johnstone and Frodin 1982).

Avicennia-Ceriops Mangrove Forest

Avicennia-Ceriops mangrove forest can occur on well-drained sandy as well as muddy substrates in the littoral zone (Johnstone and Frodin 1982). It typically occurs as extensive and continuous tracts, but can also be found as narrow fringes around saline mudflats. The dominant species in this community is *Avicennia marina*, a species with thick broad crowns and abundant pneumatophores that can form a dense ground cover in areas regularly under tidal inundation. *Ceriops*, *Aegicera*, *Xylocarpus* and *Bruguiera* are also present and tend to increase in proportion with distance inland. Where flooding is less frequent, a ground cover of *Sesuvium, Chloris* and S*porobolus* can be present.

Premna-Scaevola Scrub

This scrub type occupies sandy beach ridges located within the broader mudflat landform. It may separate stands of *Rhizophora-Bruguiera* and *Avicennia-Ceriops* or subdivide a large stand of the latter community. The community consists of tall shrubs and low trees usually up to 6m to 7m high and with representation of *Premna, Scaevola, Thespesia, Hibiscus, Clerodendrum, Gyrocarpus* and *Pandanus*. The scrub can be variably open to dense, with scrub density generally increasing with distance inland. *Pandanus* can be dominant, particularly in open situations (Heyligers 1966, 1972). An herbaceous layer that includes *Achyranthes* is often present under gaps in the canopy. Various lianes and creepers are also commonly present, including *Ipomea* and *Flagellaria*.

Clerodendrum-Flagellaria Thicket

In this thicket type an open layer of *Acacia* or *Pittosporum* (up to ~ 10m high) stands above a dense 6m to 7m high scrub of *Clerodendrum*, *Harpullia, Pluchea*, and *Hibiscus*. The ground cover, incorporating *Acrostichum* and *Chloris*, can be well developed below gaps in the shrub layer, and in places climbers such as *Flagellaria* form dense tangles. This community occurs on beach ridges, but also extends in places into depressions where it grades into the understorey of mixed littoral forest with *Ceriops* and/or *Excoecaria* additionally present as emergents (Heyligers 1966, 1972; Paijmans 1976).

Gyrocarpus-Harpullia Thicket

Gyrocarpus-Harpullia thicket is semi-deciduous and occurs on inner beach ridges within the Littoral Plains Zone. It is also found further inland where it occurs as patches within hill savannah, especially in gullies and foot-slope areas. Floristically this thicket is related to *Bombax-Celtis* forest (see below), but it differs having a more open upper layer and a denser scrub layer. The emergent tree layer includes representatives of *Bombax, Gyrocarpus, Garuga, Adenanthera, Brachychiton, Erythrina* and *Planchonella*, with occasional *Acacia, Eucalyptus alba, E. papuana, Ficus* and *Livistona*. The shrub layer includes representatives of *Harpullia, Clerodendrum, Santalum, Cycas, Alsontia, Glochidion, Pandanus* and *Myoporum*, as well as climbers including *Flagellaria*.

Sesuvium-Tecticornia Salt Marsh

This vegetation type is found on the supra-tidal mudflats, typically growing around the margin of bare ‘salt flats’ and on hummocks within these areas. These areas experience occasional saltwater inundation under exceptional high tides and freshwater flooding during high rainfall events. Saltmarsh vegetation commonly occurs as a marginal strip, either passing seawards into *Avicennia-Ceriops* mangrove forest, or landwards into grasslands. *Sesuvium portulacastrum* is present either in pure stands or in combination with *Tecticornia* species. *Sporobolus* sometimes also co-exists with *Sesuvium* (see also Paijmans 1976). Mabbutt (1965: 132) mooted that the large hummocks within the supra-tidal mudflat landform might be the remains of abandoned crab mounds.

Sporobolus-Eriochloa Grassland

Sporobolus-Eriochloa grassland is a low vegetation community that occurs around the margin of exposed salt flats and on local rises, but it also appears to form a complete cover over some parts of supra-tidal mudflats. Typically, a dense cover of *Sporobolus* occurs between scattered tussocks of *Eriochloa*, with occasional individuals or small clumps of *Cassia, Pluchea* and *Imperata*. In areas not occupied by grasses, *Sesuvium* and *Tecticornia* may occur. Transition zones to higher ground, typically on the inland margin of the Littoral Plain Zone, see the addition of *Themeda* and *Heteropogon*, as well as scattered *Pandanus*. This transitional community characteristically grades into *Themeda-Eucalyptus* savannah (see also Henty 1982).

Hyptis-Imperata Herbfield

This predominantly herbaceous community represents an early succession stage following gardening or other forms of disturbance on beach ridges and littoral sand plains. It is broadly distributed in the Caution Bay Littoral Plains zone. Weeds (*Hyptis, Sida,* and *Crotalaria*) co-exist with grasses (*Imperata, Heteropogon, Themeda, Rhynchelytrum, Eriachne,* and *Saccharum*) below remnant shrubs and low trees (*Hibiscus, Premna, Pandanus, Albizia, Timonius,* and *Leucaena*).

Imperata-Themeda australis Grassland

Imperata-Themeda australis grassland is a mid-height community that grows on sand plains of the Littoral Plains Zone. It appears to be a successional derivative of the largely herbaceous *Hyptis-Imperata* community and is distinguished primarily by an increased dominance of *Imperata* and *Themeda* (see also Henty 1982; Heyligers 1966). Paijmans (1976) regarded local high-density stands of *Imperata cylindrica* on inner beach ridges to be an essentially anthropogenic feature of the landscape.

Littoral Plains Zone Animal Resources

Sandy Foreshore Habitats

The open sandy beaches contain a low diversity of economically significant animal resources. The only economically important molluscan taxon found on sandy beaches (and exclusively so) is the Striate Beach Clam (*Atactodea striata*) (Baron and Clavier 1992: 108). Ghost and fiddler crabs (Family Ocypodidae) are also exclusive to sandy beaches. They burrow at high tidal levels or sometimes further inland in dune complexes. They are active and thus accessible mainly at night (Jones and Morgan 1994: 193). Ocypodids are mostly small crabs but they can occur in very high densities and could represent a significant food resource.

Numerous waders and other sea birds forage along the beach strandline (Woxvold 2008a: appendices 1 and 2). No mammals use the beach or foredune habitat to any extent, and the only marine vertebrates that might be encountered in this specific context as distinct from the adjacent offshore waters are several species of marine turtles (Green Turtle *Chelonia mydas*; Hawksbill Turtle *Eretmochelys imbricata*; and Leatherback Turtle *Dermochelys coriacea*) and the Saltwater Crocodile *Crocodylus porosus* (CNS 2009).

Marine turtles generally come ashore on sandy beaches only to lay eggs. In the Caution Bay area, the only record of turtle breeding comes from Idihi Island, situated 15km southwest of the mouth of the Vaihua River. This record comes from local people who claim to have harvested turtle eggs occasionally from the island, with nesting activity by Green and Leatherback Turtles said to occur in December (CNS 2008a: annex D table 1). However, no turtle tracks or nests were seen during a visit in December 2007 by Coffey Natural Systems staff (CNS 2008a: annex D table 1). The possibility must be entertained that in times past, sandy beach habitats in Caution Bay may have served as rookery sites for one or more species of turtles and that both adult turtles and eggs were available from this habitat.

Mangroves and Other Mudflat Habitats

Molluscan species that inhabit muddy bottoms of mangroves and tidal flats include the Granular Ark (*Tegillarca granosa*), Common Geloina (*Geloia erosa*), Corrugate Lucine (*Austriella corrugata*) and Telescope Snail (*Telescopium telescopium*). Tree oysters (*Isognomon* spp.) live in dense colonies, attached to rocks or trees and other hard substrates in muddy estuaries and mangroves (Poutiers 1998a: 190).

Mud Crabs (*Scylla serrata*) and other members of the family Portunidae (e.g., *Thalamita* spp., *Portunus* spp., *Charybdis* spp.) are common in mangrove habitats. They generally prefer subtidal rather than inter-tidal reaches, although juveniles often live in shallower water than adults (Jones and Morgan 1994: 155-156). In contrast, members of the family Sesarmidae (which Jones and Morgan [1994: 181-191] included within Grapsidae) usually occur inter-tidally, especially near the high tide mark. These crabs burrow in soft muddy or sandy substrates, or live under rocks and logs, and they are often found in estuaries and mangroves. Some species climb to escape predation.

The more fully aquatic fish fauna of the mangrove and estuarine habitats will be described in the account of the Inshore Marine Zone.

The recorded vertebrate fauna of mangrove forest habitats at Caution Bay consists of 20 species of birds and one snake, the Little Filesnake *Acrochordus granulatus* (see Woxvold 2008: appendices 1 and 2). However, at least one marsupial, two or more rodents, six or more bats, two other semi-aquatic snakes, two monitors as well as various small lizards, the Saltwater Crocodile, and around 60 additional birds are known to occur elsewhere within this habitat, at least on a seasonal basis (see Woxvold 2008: appendices 1 and 2). The Mangrove Monitor (*Varanus indicus*) is the largest of these mangrove forest species; although it also occurs in fully terrestrial habitats, in mangroves it feeds principally on crustaceans.

The Common Water Rat (*Hydromys chrysogaster*) is best known as an inhabitant of freshwater streams and rivers in Australia and New Guinea. However, across northern Australia it also forages into mangroves and along open sandy beaches (see account in Van Dyck and Strahan 2008). It is a generalist carnivore that consumes molluscs, crustaceans and fish, and is a capable digger, excavating conspicuous tunnel systems at water level into stream banks. A smaller relative, the False Water Rat (*Xeromys myoides*), is found regionally in mangrove habitats but not yet recorded from the Port Moresby-Caution Bay region. The nearest record is from the coast of the Trans-Fly area far to the west (Hitchcock 1998), but this species is hard to detect and may yet prove to be more widely distributed in southern New Guinea.

The occurrence of Spotted Cuscus (*Spilocuscus maculatus*) in any mangrove habitat in southern PNG is not confirmed. However, this species is reported to be locally abundant in seasonally flooded swamp forests in the lower Purari River catchment to the northwest (Liem and Haines 1977), and other species of phalangerid marsupials are known to reside in mangrove communities in northern Australia.

There are no confirmed records of flying foxes (*Pteropus* spp.) in the Caution Bay area. However, they are likely to occur at least as sporadic visitors, and it is possible that they formerly made use of the mangrove forests, as sites for seasonal courtship or maternity aggregations.

The Hinterland Zone

Mabbutt *et al.* (1965) distinguished five 'zones' within the broad, undulating lowland plain that extends for 30km or more between the coastal margin and the foothills of the Owen Stanley Range. Three of these zones occur in strict succession between the coast and the inland ranges:

1. *Coastal Hill Zone*, underlain by various sedimentary rocks, with ridges formed by limestone and cherty beds mainly near the coast, and lowlands cut largely in mudstone on the inland side. Local relief ranges from near sea level to 320m a.s.l. Annual rainfall is mainly between 1,000 and 1,200mm. Streams are ephemeral and these often terminate in flood-out areas behind the coastal barriers of the Littoral Plains Zone. Much of this zone is covered with a mosaic of eucalypt savannah and grassland, with deciduous forest or semi-deciduous thicket in gullies and on remote hills, and tall grassland and gallery forest in valleys and plains. In the vicinity of Caution Bay, this zone is represented by the strip of land that forms the local catchments of the Vaihua River, and Ruisasi Creek and Lea Lea Creek to the north.
2. *Foothill Zone,* formed on gently dipping volcanic rocks and having the general form of an uplifted and deformed 'peneplain', now dissected to produce a complex terrain of broad ridges and broad to narrower valleys, with up to 155m of local relief (Löffler 1977; Mabbutt 1965). Inland of Caution Bay, this zone includes the broad deformational basin which forms the local catchment of the westward-flowing Laloki River. Annual rainfall in this area typically exceeds 1,200mm, and larger streams and all major channels are perennial. The lower parts of the zone are covered with savannah and strongly deciduous forests, grading upward into extensive, slightly deciduous to evergreen forests.
3. *Upland Zone,* extending up to 460m a.s.l. and heavily dissected with ridges and small plateau, forming up to 230m of local relief. Inland of Caution Bay, this zone is formed of volcanic agglomerate and tuff. Local annual rainfall is approximately 1,500-2,030mm and all watercourses are perennial. The zone is largely covered with tall evergreen forest, including oak forest in the higher parts, with some slightly deciduous forests on crests and with patches of savannah in rainshadows.

Mabbutt *et al.* (1965) distinguished two other zones, both inset locally within the Foothill Zone:

4. *Fluvial Plains Zone*, formed of depositional landforms associated with the various large, perennial rivers that drain the southwestern slopes of the Owen Stanley Range. At Caution Bay, this is the Laloki River with its two major feeders, the Brown and Goldie Rivers. The fluvial plains are traversed by meandering rivers, with a tall evergreen riparian forest present on active levees. Former meander tracts have mainly mid-height to tall grassland, while back-plains and lower reaches of the zone mainly support evergreen forest.
5. *Swamp Zone*, situated in poorly drained sections of the tectonic depression that forms the local catchment of the Laloki River. It includes areas of permanent or seasonal standing water as well

as periodically flooded plains. The permanent swamps range from large basins (such as Waigani Swamp near Port Moresby) to smaller back-swamps in former meander channels. These swamps typically have floating herbaceous vegetation, tall grassland and sago palms around their margins, with surrounding mid-height to tall evergreen forest. The seasonal swamps are usually fringed by tall evergreen forest and sometimes support stands of sago palms. Periodically flooded back-plains typically support patches of mainly evergreen thicket.

Within the Hinterland Zone, the Caution Bay study area is completely inside the Coastal Hill Zone. The following account of hinterland habitats is thus focused principally on the landforms, soils and biota of the Coastal Hill Zone, with much less detail provided on the four remaining hinterland zones, all of which are located well inland of the study area. Additional information on the climate, landforms, soils and vegetation of the Foothill, Swamp, Fluvial Plains and Upland Zones can be found in Mabbutt *et al.* (1965), as well as in more general sources such as Löffler (1982), McAlpine *et al.* (1983) and Paijmans (1976) for regional climate, geomorphology and vegetation, respectively.

Hinterland Zone Landforms

The Coastal Hill Zone is a complex undulating landscape of low plateaus, hills and ridges. Local relief is usually measured in tens of meters, but there are a number of larger hills and ridges; for example, Round Tree Hill, 6.5km to the east of the Vaihua River mouth rises to over 320m a.s.l. (Figure 7.1). The following account of the landforms of this zone draws heavily on the descriptions provided by Mabbutt (1965).

The drainage net of Caution Bay is complex and appears poorly structured. In the upper catchment, watercourses are largely oriented along strike ridges. Most channels are small and all are ephemeral, but some contain pools that retain freshwater for significant periods after rain. In the lower reaches, the valleys are broader and tend to be straighter, with less obvious structural control. The drainage pattern is indicative of high run-off, much of it as sheet flow from long gentle slopes on relatively impermeable bedrock. Other than in the lowermost parts of the system, all channels are ephemeral or they display discontinuous flow between pools.

Ruisasi Creek, which drains much of the northern half of the Caution Bay study area, continues through the Littoral Plains Zone to make ocean outfall just north of the Vaihua River mouth. In contrast, the various creeks that drain the southern half of the study area are currently blocked by barrier landforms positioned inland of the Vaihua River mouth. When in flow, these creeks debouch onto and fill a series of supra-tidal mudflats that encircle the mangrove-lined Vaihua River inlet, with the flow making its way seaward via ephemeral channels as well as subsurface seepage (see also Pain and Swadling 1980).

Further inland, Roku Creek, which drains the northeast corner of the Caution Bay study area, flows northwest to join Lea Lea Creek.

The landforms of the Coastal Hill Zone owe their initial genesis to uplift and deformation of a marine plain. According to Mabbutt (1965: 114), the plain was probably formed subaerially; remnants of degraded coral reef are today concentrated on broad interfluves. Duricrust relics also occur on higher surfaces, while in places stable foot-slope sediments show signs of lateritic weathering. Mabbutt (1965: 114) regarded these varied features as evidence of prolonged exposure and weathering through both subhumid interglacial phases and drier glacial phases through the Quaternary.

The bedrock formations of the Coastal Hill Zone at Caution Bay have not been mapped in detail, but include formations of both Cretaceous to Palaeocene age (cherty limestones, mudstones, gabbro, and volcanic tuff) and Miocene age (thick-bedded, crystalline limestones, marls, conglomerates, and some volcanic tuff), with the latter probably predominant in terms of land area (Speight 1965). All sedimentary units display steep dips. In many places these are mantled by coral rubble of Pleistocene age.

Following Rowe *et al.* (2013), the heterogeneous Coastal Hill Zone at Caution Bay is here subdivided into three distinct landform complexes: a Coastal Lowlands Complex, a Hill-Ridge Complex and an Alluvial Plains Complex. These complexes correspond in part with Mabbutt *et al.*'s (1965) *Fairfax*, *Hanuabada* and *Boroko* land systems, respectively.

The Coastal Lowlands Complex

The Coastal Lowlands is the predominant landform complex in the Caution Bay catchment. It includes the landforms created by weathering and fluvial dissection of the raised marine plain, producing low plateaus, rounded hills and ridges, and a weakly entrenched drainage net of primarily ephemeral streams.

Mabbutt *et al.* (1965: 30) provided the following brief description of the typical geology of the *Fairfax* land system: 'In the south-west, thick-bedded, crystalline limestone and soft marl, with steep dips; in the north-east, coarse conglomerate of mixed rocks, generally intensely silicified; both of Neogene age (?Siro beds). Extensive coral rubble of Pleistocene age'.

The Siro Beds consist of pebbly sandstone and coarse boulder conglomerates, notably quartz, igneous rocks, schist, chert, and feldspar grains (Glaessner 1952; Speight 1965). Candidate beds for the 'thick-bedded, crystalline limestone and soft marl' include the Miocene Boira tuff and limestone group that was characterized from near the village of Boera at the southern end of Caution Bay. It is a coarse-bedded sequence that includes tuffaceous grit, gravelly limestone grit, limestone blocks, and massive limestone (Glaessner 1952). The dominant strike is north to northwest, the dip is moderate at high angles to the east, and the limestone units are richly fossiliferous, containing abundant foraminifera of lower Miocene age.

Other regionally occurring Miocene formations include:

1. The Gidobada series (Stanley 1919), which is an ill-defined group of volcanic rocks that also includes one bed of pink coralline limestone of possible lower to mid-Miocene age; it dips moderately to the northwest (Pieters 1982; Speight 1965).
2. A thick conformable sequence comprised of the Kaieu greywacke, the Bokama limestone, the Diumana limestone, and the Vanuamai siltstone (Speight 1965) that, according to Speight (1965), is extended northwest as far as Yule Island by correlated but unnamed beds.

Much of the local topography of the Coastal Lowlands Complex is probably the expression of contrasting harder and softer beds (Mabbutt 1965). Drainage lines are aligned with the dominant strike, especially in the upper catchment area, and are often formed in fine-grained and softer rocks of the sedimentary series such as mudstone and marl. These break down uniformly to produce fine-textured sediments. Ridge profiles tend to be smooth and ridge crests are typically rounded. Free-standing rock faces are small or absent.

Slope form reflects structural control, especially dip. As expressed by Mabbutt (1965: 111):

> … the characteristic form is the strike ridge with a somewhat rectilinear dip slope and a concave escarpment steepening to about 27° and becoming rectilinear in its upper part. The escarpments are typically shallowly embayed by parallel primary valleys with open alcove-shaped heads lacking channels and more narrowly incised lower sectors which tend to open out on foot slopes. A short basal concavity connects the lower hill slope to the foot slope, which is characteristically less than 5°.

Rock outcrops are mainly limited to boulder chert bands on ridge crests and upper slopes. However, loose, essentially unaltered rock lies near the surface on most Caution Bay hill slopes. Soils are typically thin and generally dry. Mass movement is subordinate to slope-wash as an erosional process and true colluviums are generally absent at the base of hill slopes. On most hill slopes an abrupt basal concavity gives way to a smooth, concave foot-slope on which is found a mantle of fine slope-wash sediments.

The Hill-Ridge Complex

The Hill-Ridge Complex is characterized by greater overall relief and by precipitous terrain that is subject to slumping and rock falls. It is deeply incised with fairly closely spaced valleys that carry flow only after heavy rainfall. Small areas of the Caution Bay catchment area qualify as Hill-Ridge Complex.

Mabbutt *et al.* (1965: 30) provided the following brief description of the typical geology of the *Hanuabada* land system: 'Thin-bedded limestone, siltstone, and sandstone, very cherty except in the north-west; striking NW and dipping steeply NE; Upper Cretaceous to Lower Miocene (including Bogara limestone, Barune sandstone, Port Moresby group, Boira limestone)'.

The Bogara limestone and Barune sandstone are lenses associated with the regionally prominent Port Moresby group of Upper Eocene age (Glaessner 1952). The Port Moresby group as described by Speight (1965: 100) includes 'nummulitic limestone with silicified lenses, limestone metamorphosed up to garnet-pyroxene grade, and beds of green and red mudstone and calcareous sandstone'. As a second major class of rocks, it includes 'hard chert, either massive and concretionary or thin-bedded, which lenses into cherty mudstone; these cherty rocks are interbedded with soft mudstone and marl, and are characterized by intraformational slumping and the formation of chert balls and rolls'. The rocks of the group show 'a north-west strike and high angles of dip generally to the north-east'.

The Alluvial Plains Complex

The Alluvial Plains Complex comprises alluvial plains and swamps, with elevations ranging from ~ 15m to 30m a.s.l. These landforms variously occur in inland strike vales, along the lower reaches of the drainage systems, and behind the coastal barrier systems of the Littoral Plains Zone. Many zones of alluviation are discontinuous, but larger continuous floodplains of silty alluvium occur along the lower reaches of the larger, near-perennial streams, as well as along the Vaihua River (see also Pain and Swadling 1980). Where floodplains are defined, the margins slope to varying degrees and are generally well drained.

At the Vaihua River mouth, the fluvial plain extends into the littoral zone. Well developed landforms such as levees, grassy plains and small swamps are present, resulting in a variety of fluvial landforms within a relatively small area. The riparian habitats of the Vaihua River inlet are flooded each year for short periods, while more extensive inundation flows out over the surrounding mudflats and even back onto the lowermost alluvial plains, where the soils are consequently mottled (see also Pain and Swadling 1980).

The dominant geomorphic process in this landform is down-system fluvial transport of fine-textured alluvium. Although the sediments are derived ultimately from weathering of fine-textured sedimentary rocks, because most slopes in the catchment retain a soil mantle, the more proximal determinant of sediment budget within the fluvial system are: 1) rates of soil erosion from slopes; and 2) the competency of the fluvial system to move sediment through the system. The two are probably related insofar as denuded slopes subject to higher rates of erosion will also create stronger runoff and more extreme flows through the system, thereby increasing the short-term competency of the system.

In the highest reaches of the Caution Bay catchment, valley-floor sediments consist of coarser-textured deposits left behind after winnowing of finer sediments and emplaced through a combination of small-scale mass movement and local slope wash. By contrast, recent sediment build-up in the lower reaches of the system are typically fine silts and clays. These are often underlain by coarser-textured deposits. This repeated profile is suggestive of headward encroachment of fine-textured alluviation into the Caution Bay catchments (Mabbutt 1965: 115). Possible reasons for this trend include a change in base level (the level to which a fluvial system is graded, usually sea level, sometimes a lake) and local deformation, but the more likely reason, given the short time frame, is an increased sediment input into these systems leading to overload of the competency of the system. Colonization of the fine-grained sediments by herbaceous vegetation and/or grasses might also serve to reduce flow rates and entrap more sediment, thereby hastening the process of siltation.

Surveys of the freshwater drainages of the Caution Bay catchment in the 2007 dry season found the headwater reaches of each of the Vaihua River and the Karuka/Mokeke Creek systems (including Roku Creek in the study area) to consist of remnant stagnant pools in channels incised 1-2m below the alluvial plains (Hydrobiology 2008: figure 3.5). In lower reaches of these systems, some short sections of flowing freshwater were observed. The authors of the report speculated that these remnant, largely disconnected pools would be reconnected during the wet season and, further, would establish biological continuity with the estuarine environment of the Vaihua River.

Hinterland Zone Soils

The Coastal Hill Zone features a wide variety of soil types that reflect the interplay of a diverse lithology, landscape history and contemporary geomorphic processes. The following accounts are drawn from the descriptions of Scott (1965) and Mabbutt (1965), supplemented with observations made during the Caution Bay archaeological excavations.

The depositional landforms of the Alluvial Plains Complex range from poorly drained massive clays in low-lying swampy areas to silty clays on moderately well-drained surfaces and cracking clays on older alluvial surfaces with little if any active deposition. Alluvial soils derived from volcanic and sedimentary rocks are typically fine-textured, while those originating from metamorphic rocks are texturally more variable and can include a significant sand fraction.

The primarily erosional landforms of the Coastal Lowlands and Coastal Hill-Ridge Complexes typically have shallow lithosol soils. Fine-grained sedimentary rocks typically produce neutral fine-textured soils, while limestone produces alkaline soils. Lower slopes have texture-contrast or brown-clay soils of varying depth derived from colluvium and/or weathered parent material.

Soils of the Coastal Lowlands and Coastal Hill-Ridge Complexes

Four of the main soil groups distinguished by Scott (1965) are represented in the Coastal Lowlands and Hill-Ridge Complexes at Caution Bay:

Lithosols

The lithosol soil group consists of shallow soils overlying variably weathered parent rocks. They occur on slopes and ridge crests and show a close relationship to the texture, chemistry and dip of the parent rock. In areas such as Caution Bay with complex bedrock formations, different lithosols can occur on the same hill slope. Three lithosol soil families, based on colour and soil reaction, occur within the Caution Bay catchment:

1. *Alkaline dark lithosols* are derived from crystalline and muddy limestone, calcareous tuff and calcareous sandstone. They are black to greyish brown sandy loams to clays with crumbly to fine subangular blocky structure. They are moderately alkaline. At depths rarely exceeding 15cm, the soil passes abruptly or gradually into parent rock with variable degrees of weathering. Gravel lenses and isolated stones can be present in the profile, and surficial outcrops of bedrock also occur.

2. *Neutral brown lithosols* are derived from gabbro and tuff. They are dark brown to greyish brown sandy clay loams to clays with crumbly to fine subangular blocky structure and neutral reaction. These soils overlie weathered rock at depths of 15cm to 30cm. Gravel lenses and isolated stones may be present, but rock outcrops are uncommon.
3. *Neutral red lithosols* are derived from cherty shales. They are brown to reddish brown sandy clay loams to clays with crumbly texture and a neutral reaction. They overlie red-weathering rock and are often gravelly (see also Eden 1974).

Red Gravelly Clay Soils

Soils of this group have reddish brown gravelly or stony upper horizons overlying gravel-free, red lower horizons. Many are probably polygenetic, the upper horizons being transported colluvium and the lower horizons being the product of in situ soil genesis. In many cases, the colluvial layer appears to derive from cherty shale, while the lower horizon is made of weathered shale or tuff. Some soils within this group lack the clear separation of horizons; these tend to be found on upper foot-slopes and lower hill slopes, in positions subject to seepage and run-on from higher ground.

Scott (1965: 140-141) identified two families in this group, distinguished on the basis of soil reaction:

1. *Nebrie Family* soils are moderately alkaline throughout. They exhibit strong texture-contrast between a very gravelly, dark brown reddish brown sand clay loam to clay overlying dark red, massive, plastic clay in which fragments of weathered rock may occur. Weak stone-lines are sometimes present between the two horizons. These soils are moderately permeable.
2. The *Bom Family* soils are similar to the foregoing, but are neutral to slightly acidic (see also Eden 1974).

Brown Clays

Brown Clay soils are found in the hills of the Coastal Hill Zone. These are mainly non-gravelly soils of moderate depth, derived from in situ or short transport of relatively soft parent rocks.

Scott (1965: 140-141) identified two families in this group, distinguished on the basis of soil reaction which in turn reflects the parent material:

1. *Fairfax Family* soils are formed on and derived from calcareous tuff or coral limestone. They are located across undulating plains to upper foot-slopes. The surface material is black to dark brown sandy clay to clay, with moderately crumbly structure, which grades at a depth of 10cm to 20cm into more plastic sandy clay to clay with subangular blocky structure. Calcareous concretions are typically present in the lower horizon. Occasional fragments of chert and/or lenses of quartz gravel are also present. Underlying these materials is weathered bedrock, varying in colour from yellowish brown to dark greyish brown and with a similar sandy to sandy clay texture. The regolith layer includes common carbonate concretions. Soil reactions are mildly alkaline at the surface, becoming moderately alkaline with depth. Permeability is moderate to slow.
2. *Bomana Family* soils are similar to the foregoing family, but the soil reaction is neutral to very strongly acid, and calcareous concretions are absent. These soils derive from the weathering of tuff and gabbro. They occur on undulating plains, upper foot-slopes, and rounded rises (see also Dearden 1987).

Texture-Contrast Soils

Texture-contrast soils feature a coarse-textured surface horizon abruptly overlying finer-textured subsurface material (see also McKenzie *et al.* 2004). They occur on foot-slopes extending to stable interfluves in the Coastal Hill Zone and to a lesser extent in the Foothill Zone. These soils have slow permeability. In the wet season they tend to become boggy, but after prolonged dry periods the surface horizon hardens and can produce rapid run-off of breaking rains. Concentrations of quartz and chert gravel are sometimes present in the A horizon. Scott (1965: 141) subdivided this group according to soil reaction, followed by the presence-absence of a bleached A_2 horizon.

3. *Ouou Family* soils have an A horizon of very dark grey to brown sandy loam to sandy clay loam with crumbly structure, merging into grey to light greyish brown, massive compact, sandy loam to sandy clay loam with frequent mottling. An abrupt transition is observed at 200mm to 400mm to the B horizon which has weakly developed columnar structure, ranging in colour from dark grey through brown to yellowish brown and with frequent mottling, varying in colour from yellow to red. Texture in the B horizon varies from sandy clay to heavy clay. Soil reaction varies from neutral to mildly alkaline in the A horizon to strongly alkaline in the B horizon. Carbonate concretions are restricted to the B horizon and become more frequent with depth.
4. *Ward Family* soils are similar to the foregoing but lack a distinct A_2 horizon and any mottling within the A horizon. These features may be indicative of better drainage (Scott 1965: 142).

Soils of the Alluvial Plains Complex

Four of the main soil groups distinguished by Scott (1965) are represented in the Alluvial Plains Complex at Caution Bay:

5. *Alkaline olive silty clays*. These are moderately well-drained alluvial soils that occur on elevated plains subject to occasional flooding. Through the wet season these areas may experience high water-tables, and low permeability may result in persistent surface water. There is little active deposition on these surfaces. They are dark-coloured, weakly crumbly to massive silty clays that merge with depth into paler massive silty clays. Darker surface bands, probably representing buried A horizons, are occasionally present. Mottling and alkalinity increase with depth, and calcareous concretions may be present. This soil family is widely observed on alluvial landforms.
6. *Neutral olive silty clays*. These are similar to foregoing group but differ in being neutral to slightly acidic, probably reflecting contrasting parent materials.
7. *Grey sticky clays*. These are typically found in depressions subject to frequent inundation. These consist of grey to dark grey massive clays, often with a surface peaty layer composed of fibrous root matt or peaty clay. Gleying (Fe reduction) can occur with depth, sometimes producing mottling at depth. These soils are neutral.
8. *Dark cracking clay soils*. These are formed on older, stable alluvial surfaces where there is little or no active deposition or erosion. They exhibit seasonal cracking. Scott (1965: 137-138) distinguished three soil families in this group:
   a. *Boroko Family* soils are black to very dark grey heavy clays with a blocky surface layer that dries to produce cracking up to 4cm wide. These soils are moderately alkaline at the surface, increasingly so with depth. Calcareous concretions are common, especially at depth. Lenses of rounded gravel may occur at depth, demonstrating the alluvial origin of the sediments.
   b. *Jackson Family* soils are similar to the foregoing, but they are neutral from the surface to a depth of almost 1 m, becoming alkaline only at greater depth. They occur in similar contexts to the Boroko soil family and may be formed on sediment of contrasting parent lithology.
   c. *Inapi Family* soils generally occur upslope from the Boroko and Jackson families. These soils are formed on sandy to heavy clays and feature a thin hard-crumbly surface horizon that shows minor cracking on the surface and more prominent cracking below (see also Mohr *et al.* 1972). In wetter locations the surface layer is more organic and friable. Calcareous concretions are frequently observed at depth, together with slight mottling.

Hinterland Zone Plant Communities

The Coastal Hill Zone is in broad terms a 'savannah landscape'. However, this description belies a considerable diversity in plant communities that is underpinned by a range of natural and anthropogenic factors. The interplay of these factors is discussed at some length in a later section of this chapter.

Four broad categories of vegetation are distinguished here, following the structural categories of Specht (1981, 1983) and Gillison (1983) and defined as follows:

1. Savannah: Plant formations that combine a ground layer dominated by graminoids and a woody plant component over 3m tall with non-intersecting crowns. The term 'woodland' is often used interchangeably (Walker and Gillison 1982). The Savannah category can be subdivided as follows:
   - *Woodland savannah* with >0.2% cover of single-stemmed woody plants over 3m tall and a >2% graminoid cover.
   - *Very low woodland savannah* with >0.2% cover of trees <3m tall. Pandanus and palms may be dominant in the tree layer.
   - *Shrub savannah* with >0.2% cover of multistemmed woodland plants and a >2% graminoid cover.
2. Grassland: Graminoid-dominated formations where woody plants are present only as widely-spaced individuals (up to 0.2% cover). The term 'Grass Savannah' can be employed interchangeably. The Grassland category can be subdivided according to height, into low (<1 m), mid-height (<2 m) and tall grassland (>2 m). Shorter grasslands tend to be more species-rich than taller grasslands. Grasslands grade into savannah or scrub as woody cover increases above arbitrary thresholds (see below). Legumes often occur among the grasses during recovery after burning (Heyligers 1965, 1966).
3. Scrub and thickets: Plant formations where multi-stemmed plants form one or more distinct layers and where the cover provided by the tallest shrub layer is sparse (<30%), mid-dense (30%-70%) or dense (>70%).
4. Forest: Plant formations dominated by trees forming one or more distinct strata and where the cover provided by the tallest tree layer is mid-dense (30%-70%) or dense (>70%) (Heyligers 1965; Specht 1983). Further categorization is based on tree height: 'tall' forest exceeds 30m,

'mid' forest ranges from 10m to 30m, and 'low' forest ranges from 5m to 10m (Specht 1983). With increasing height the evergreen forest formations at Caution Bay become increasingly tiered. Low evergreen forests are either mangrove vegetation or woody regrowth communities. Mid-height evergreen forests are taller mangrove vegetation or forest occurring on estuarine margins or around swamps. Tall evergreen forest is limited to areas where soil moisture is available year round (Paijmans 1976). Forests of the Caution Bay area are further subdivided according to the proportion of deciduous tree species, as well as their behaviour, i.e., whether the species are slightly or strongly deciduous.

5. Mixed herbaceous vegetation: Plant formations where non-graminoid herbs are dominant. At Caution Bay, these communities are most common in the Littoral Plains Zone but some extend into the Alluvial Plains Complex of the Coastal Hill Zone, while others are associated with freshwater pools in ephemeral streams.

Savannah Communities

Savannah communities are found on all landforms within the Coastal Hill and Foothill Zones. The accounts of each community in this and subsequent vegetation categories draw heavily on Heyligers (1965).

Themeda australis-Eucalytpus Savannah

This savannah covers extensive areas of the Coastal Hill Zone and is also present in the Foothill Zone. It is found on a variety of landforms including ridges and hill crests, slopes, and undulating plains. Grasses can reach 1m in height and *Themeda australis* is predominant. Tussock spacing varies from open to dense. In communities with open spacing, *Sehima nervosum* is codominant and *Eriachne*, *Stipa* and *Cymbopogon* also occur. Forbs (broad-leaf herbs) are scarce. *Themeda australis* has a preference for dry sites, although it is able to tolerate waterlogging for short periods.

Predominant tree species are *Eucalyptus alba, E. confertiflora* and *E. papuana*. Secondary tree species include *Albizia, Timonius* and *Antidesma*. With distance inland, this community grades toward deciduous forest (see also Heyligers 1966, 1972).

Ophiuros-Eucalyptus alba Savannah

This community occurs across numerous landforms in the Coastal Hill and Foothill Zones, and is commonly found on crests, slope-lines and drainage depressions (see also Heyligers 1966; Paijmans 1976). The grass layer attains heights to 1m and incorporates equal proportions of *Ophiuros* and *Themeda*, with patches of *Heteropogon*, *Sorghum*, and/or *Imperata* possibly indicative of disturbance (Heyligers 1965: 158). Forbs are rare and usually limited to members of Papilionaceae. Tree cover varies in composition and density, and typically includes *Eucalyptus alba* and one or other of *E. confertiflora* and *E. papuana*. *Albizia* and *Acacia* are uncommon associates. More frequently found in this community are *Antidesma*, *Timonius* and *Desmodium*, all growing to lesser height. *Cycas* also occurs in the context of a very open shrub layer.

Themeda novoguineensis-Eucalytpus Savannah

The grass *Themeda novoguineensis* is the primary defining element of this community that occurs on a variety of landforms in the Coastal Hill and Foothill Zones, including rocky crests, slope-lines and drainage depressions (see also Heyligers 1966). *Ophiuros* species are absent and *T. australis* occurs only in low abundance. In damp situations additional grass species are present (*Panicum, Arundinella, Imperata, Heteropogon, Eriachne,* and *Eulalia*) along with a variety of forbs (*Indigofera*, *Desmodium*, *Zornia*, and *Tephrosia*). The tree layer is lower than in other savannah communities and consists of *Eucalyptus alba, E. papuana, E. confertiflora, Albizia, Desmodium* and *Antidesma*. An open shrub layer includes canopy tree seedlings, *Cycas*, myrtaceous shrubs and representatives of Papilionaceae.

Mixed Savannah

Mixed savannah is sometimes present at the interface between other savannah formations and evergreen and/or deciduous forest. The structure and floristic composition varies according to local relief and drainage, and possibly with the frequency of burning. On well-drained undulating terrain it is as tall as the evergreen or deciduous forest that it fringes, but it contains fewer species. The commonest trees are species of *Tristania*, *Melaleuca*, *Acacia* and *Xanthrostemon.* Eucalypts are present but never abundant. Tall shrubs including *Choriceras* and *Helicteres* may be present, along with a variety of tall grasses including *Imperata, Ophiuros* and *Ischaemum*. Trees are irregularly spaced but denser than in the more typical savannah categories. On flatter, poorly drained terrain, the mixed savannah is typically lower and more open. It grades into sedge-grassland with increasing moisture levels. *Melaleuca, Banksia, Grevillea,* and notably *Pandanus* become more abundant along the gradient of increasing moisture. *Pandanus* is often the only tree species in the final transition to sedge-grassland. *Melaleuca* savannah has been described elsewhere on low-lying seasonally inundated flats adjacent to the littoral zone; in some examples *Melaleuca viridiflora* grows as pure stands of thin trees over a ground cover of grasses and sedges (see also Johns 1982; Paijmans 1976).

Grassland Communities

Ophiuros-Imperata Grassland

This mid-height grassland occurs as dense mixed stands of *Ophiuros* and *Imperata*, usually without other grasses. However, *Saccharum* species may co-occur near forest margins or in localized depressions. A sparse overstorey of low shrubs including *Melastoma, Crotalaria* and *Glochidion* as well as *Cycas* is often present, along with occasional small trees (*Timonius*, *Antidesma*, *Pandanus*, and *Nauclea*). This community occupies quite large areas on low-lying alluvial plains and may extend onto relict plains of the Coastal Hill Zone (see also Henty 1982). Heyligers (1965: 156) understood this community to be maintained if not produced by a history of repeated burning and gardening.

Saccharum-Imperata Grassland

This tall grassland community is usually dominated by *Saccharum spontaneum*, but *Imperata cylindrica* may be prominent in areas that have been recently burnt (*Imperata* is the first to sprout after burning) and in areas subject to episodic waterlogging. *Saccharum* grows to a height of 3.5m and *Imperata* to over 1.5m. Herbs and other grasses are largely excluded by the dense shade below the tall, dense sward. Fire-tolerant trees and/or shrubs are often present as scattered individuals, with *Albizia, Nauclea, Antidesma, Melaleuca* and *Pandanus* prevalent.

Saccharum-Imperata grasslands are widespread on alluvial plains of the Coastal Hill Zone, but they also extend onto surrounding slopes wherever sufficient moisture is available (e.g., foot-slopes, forest borders; see also Henty 1982). This grassland community is very prone to firing (Gillison 1983; Paijmans 1976). Paijmans (1976) considered it to be a product of repeated burning and gardening with consequent reduction of tree cover.

Phragmites-Saccharum Grassland

This tall community is variably categorized as grassland (e.g., Heyligers 1965) or as grass-swamp (e.g., Paijmans 1976). It is variably found in permanent swamps through to poorly drained areas subject to seasonal flooding. Wetter sites typically have more *Saccharum* that does not tend to survive extended dry periods. The grasses often occur together with ferns (*Cyclosorus*) and lianes/creepers (Convolulaceae, *Cayratia, Flagellaria,* and *Lygodium*). Scattered trees and/or shrubs may be present (*Glochidion, Nauclea, Antidesma,* and *Melaleuca*) along with *Livistona* palm.

Scrub and Thickets

Garuga-Rhodomyrtus Thicket

Small patches of this community occur on lower-lying areas of the Coastal Hill Zone. Scattered deciduous trees are present over thin shrubs. Among the emergent trees, *Garunga* is dominant, with occasional *Adenanthera, Bombax, Ficus,* and *Gyrocarpus*. *Rhodomyrtus, Celtis, Psychotria, Antidesma, Desmodium, Canthium, Pittosporum, Alstonia, Eucalyptus alba, Trema and Cordia* are present in the shrub layer. Numerous lianes may be present. A groundcover herb, *Oplismenus*, is recorded growing with ferns.

Adenanthera-Colona Thicket

In this semi-deciduous thicket, the scrub layer is dominated by *Colona*, with *Harpullia, Celtis, Glochidion* and *Lagerstroemia* usually present. *Adenanthera* is the most common emergent, with occasional *Terminalia, Garuga* and *Grevillea*. The understorey includes a range of small-leaved shrubs, along with lianes and other climbers. Ground cover consists of sedges, *Oplismenus*, and scattered ferns. This community occurs as patches within the undulating plateau and hill savannah of the Coastal Hill and Foothill Zones.

Forest Communities

Bombax-Celtis Forest

This 'strongly deciduous' community features an emergent canopy of deciduous trees (*Bombax, Gyrocarpus, Brachychiton, Adenanthera, Garuga, Erythrina,* and *Terminalia*) that gives it a seasonally 'open' appearance. However, a well-shaded internal environment is created by a lower canopy layer of evergreen and semi-deciduous trees including *Celtis, Santalum, Micromelum, Colona, Dysoxylum, Harpullia, Ficus, Terminalia, Mallotus, Cryptocarya, Canarium, Sterculia* and *Myristica*, and a variably open to dense shrub layer formed mainly of shrub-lianes and *Flagellaria*. Ground cover is patchy and consists of forbs and ferns. Rare epiphytes are present. *Bombax-Celtis* Forest is confined to the Coastal Hill and Foothill Zones, along drainage lines and associated plains (where it grades into wooded savannah), gullies in tracts of savannah, as well as foot-slopes (see also Paijmans 1976).

Planchonia-Adenanthera Forest

Planchonia-Adenanthera Forest is a slightly deciduous community found on alluvial plains, outwash flats and foothills of the Coastal Hill Zone. It is the lushest of the forest types in Caution Bay. It combines an open emergent layer of *Planchonia, Adenanthera, Casearia, Pangium, Nauclea, Alstonia, Pterocarpus,* *Ficus, Sterculia, Terminalia, Bombax* and *Garuga*, with a denser lower canopy layer of *Kleinhovia, Ficus, Jagera, Barringtonia, Semecarpus* and *Pleomele*. The lower canopy averages 30-35m in height with taller emergents that have notable buttress formations and wide crowns. Shrub and herbaceous ground layers are sparse under dense canopy and better developed in areas with greater light penetration. The understorey layers feature *Pseuderanthemum, Pandanus,* Zingiberaceae and *Arenga*, along with numerous lianes. Palms are rare.

Melaleuca-Nauclea Forest

This community occupies poorly drained depressions in the alluvial landforms at Caution Bay. It combines a thin and irregular upper canopy, an open secondary canopy, and a denser shrub layer. The upper canopy is floristically diverse and incorporates *Melaleuca, Nauclea, Erythrina, Terminalia, Alstonia, Plancpnia, Ficus, Sapium, Acacia* and *Livistona*. Lower canopy elements include *Kleinhovia, Premna, Semecarpus, Pandia, Macaranga, Hibiscus* and *Pandanus*. *Livistona* and *Areca* palms are sometimes present. The shrub layer is dominated by palms including climbing forms, *Flagellaria, Cordyline* and tall Marantaceae. This forest type is closely related to the 'lowland mixed swamp forest-woodland' recognized by Paijmans (1976).

Octomeles-Artocarpus Forest

This forest community occurs on flood-out zones on the alluvial plains (see also Paijmans 1976). An open upper canopy includes species of *Octomeles, Artocarpus, Terminalia, Ficus, Nauclea, Intsia, Pometia, Planchonia, Alstonia, Pterocarpus, Dracontomelum, Spondias* and *Bischoffia*. A secondary canopy contains mainly *Kelinhovia* and *Artocarpus*, with scattered *Horsfieldia, Ficus, Dysoxylum, Macaranga, Sterculia* and *Livistona*. Lianes and climbing palms are common. The understorey is patchy and varied, and includes *Pandanus* and representatives of Zingiberaceae, Marantaceae and Musaceae. Species of *Cyclosorus*, *Stenochlaena* and *Paspalum* and representatives of Araceae form a thin ground cover. Heyligers (1965: 167) mentioned that *Octomeles-Artocarpus* Forest is often disturbed by shifting cultivation on account of its favourable topography and soil associations.

Freshwater Plant Communities

The freshwater streams of the Coastal Hill Zone are highly dynamic environments for plant growth. Stream flow is strongly episodic and floodwaters are usually silt-laden. Sedimentation encourages the development of successional plant communities rather than the establishment of stable communities. Plant succession on wetlands may be retarded by dry season fires (Henty 1982; Johns 1982; Paijmans 1976).

The vegetation of standing or slowly moving freshwater consists of either floating or submerged plants. Free-floating aquatics found in streams and pools of the Caution Bay catchment include *Lemna, Azolla, Pistia* and *Utricularia*. These grow either in mixed communities or in a mosaic of single-species colonies. In shallower water, rooted herbaceous communities tend to establish, with sedges, herbs and ferns dominant in water that is frequently stagnant, and grasses predominant in more typically flowing water. Common non-graminoid rooted taxa of the Caution Bay catchment include species of *Ceratophyllum, Nymphaea* and *Nymphoides* (Heyligers 1965; Paijmans 1976). Swamp grass communities, already described above, form dense cover over alluvial plains that are subject to regular shallow flooding.

Vegetation Dynamics of the Coastal Hill Zone

The savannah vegetation of southern New Guinea has long been a focus of debate regarding its origins, with variable emphasis placed on the contrasting roles of natural climatic controls and anthropogenic influences. Heyligers (1965: 170-173) regarded natural variation in soil moisture budget through the year to be the primary determinant of most non-graminoid vegetation types (i.e., not including dry land grasslands and savannah) in the southern lowlands of New Guinea, with the duration of periods of water stress being the primary limiting factor for evergreen versus deciduous communities. For savannah, mid-height grassland, and tall grassland, by contrast, he concluded that their patterns of occurrence are 'not reliable indicators of climate and soil conditions because of the overriding influence of repeated burning' (Heyligers 1965: 170). However, he stopped short of declaring the savannah-grassland communities to be entirely a product of their fire history. Interestingly enough, Mabbutt (1965) seemed to favour the opposing view in his summary of the diverse information derived from the land systems survey. He included savannah with semi-deciduous thicket and strongly deciduous forest as communities whose occurrence is determined by 'edaphic drought due to mainly shallow or fine-textured soils' under a climate of relatively low rainfall (Mabbutt 1965: 17).

Later authors including Eden (1974) and Paijmans (1976) clearly viewed the evergreen and deciduous forests of the Port Moresby-Caution Bay region as remnants of formerly more continuous woody vegetation cover that had become fragmented through a combination of clearance for gardening and burning. Eden (1974) observed that the distribution of savannah and grassland vegetation in the Port Moresby-Caution Bay region could not be accounted for entirely by environmental factors. He suggested that these plant communities had at least expanded as a consequence of anthropogenic burning associated with shifting cultivation and hunting. However, like Heyligers (1965), Eden (1974) remained uncertain as to the origin of the local savannah communities and left open the possibility that they had some natural occurrences. By contrast, Oram (1977: 83) seems more certain in his statement that the savannah and grasslands along the coast between Boera and Lea Lea (i.e., the Caution Bay hinterland) existed 'probably as a result of human occupation'. Allen (1977a, 1991) has emphasized the importance of firing of the grassland communities as a specific method for hunting the Agile Wallaby (*Macropus agilis*) which was not only consumed locally, but following preparation through smoking, was also used as a trade commodity. The use of fire in wallaby hunting activities within the Caution Bay was mentioned specifically by informants and is reported in more detail in Chapter 5 of this volume.

The potential ecological role of fire in this context needs to be considered in relation to three different ecological processes, namely 1) the initial destruction of forest in areas that are climatically suited to its growth; 2) the maintenance of non-forest habitats; and 3) the exclusion of savannah tree species that are climatically suited to their growth.

Although many broad-leaf forest species are tolerant of seasonal drought, the majority do not possess either the physiological or regenerative capacity to survive and recover from burning. It is this extra ability that represents the key adaptive trait of savannah woodland plant species and distinguishes them from other forest plant species (see Gillison 1983 for a review of such features). Many grasses also display this ability as a result of the long evolutionary association of the grasses with savannah communities since the Miocene. Within savannah habitats, fire typically destroys the above-ground biomass of grasses but has little impact on the root systems that quickly reshoot as soon as new moisture is available (Gillon 1983). Trees may experience little impact or they may suffer partial defoliation. In the hottest fires where the trunks are also damaged, sprouting generally can occur from epicormic buds within the bark.

While fire can destroy individual forest trees and shrubs, a moist forest community as a whole, as well as many of its component plants, is relatively non-flammable and most fires are either unable to get established within the forest or to penetrate far into it. Accordingly, in a mosaic of forest and savannah, burning generally serves to maintain established boundaries rather than play a key role in forest conversion.

The destructive impacts of firing can be amplified when it follows the prior death or removal of forest. Forest trees can die of water stress *en masse* during prolonged droughts such as those that occurred during the last extreme El Niño event in the mid-1990s (Allen and Bourke 2009). Following loss of the canopy foliage, the forest understorey typically desiccates to the point where it will support fire; large areas of formerly forested terrain were effectively denuded as a consequence of this climatic event. Various 'dieback' diseases of trees might also have comparable effects.

Forest removal in the lowlands generally occurs through shifting cultivation (Eden 1974). Understorey shrubs and smaller trees are generally piled up after being cut and, once dry enough, they are burnt. The fire often kills shrubs and trees around the perimeter of the garden, thereby increasing its area of impact.

Gillison (1983) used a combination of aerial and ground surveys in the plains and foothills surrounding Port Moresby-Caution Bay to infer the following five-stage ecological pathway from deciduous mixed forest to eucalypt savannah:

- Stage 1: Semi-deciduous vine forest on interfluves commonly with Anacardiaceae (*Dracontomelon, Mangnifera,* and *Pleiogynium*), Bombaceae (*Bombax, Salmalia*), Burseraceae (*Canarium*), Combretaceae (*Combretum, Terminalia*), Dipterocarpaceae (*Anisoptera*), Fabaceae (*Albizia, Pterocarpus*), Hernandiaceae (*Gyrocarpus*) Proteaceae (*Finschia, Helicia*) and Sterculiaceae (*Firmiana, Sterculia*).
- Stage 2: Clearing of this community for subsistence gardening, followed by periodic burning, leading to tall grassland savannah.
- Stage 3: Invasion of short-lived, scattered low trees such as species of *Antidesma, Desmondium, Kleinhovia,* and *Timonius*.
- Stage 4: Increase in fire frequency with some elimination of low trees and gradual increase in short grasses. First appearance of eucalypts.
- Stage 5: Dominance on interfluves of eucalypts (*Eucalyptus alba, E. confertiflora,* and *E. papuana*) and scattered woody understorey genera such as *Atylosia, Cycas, Desmondium, Timonius* and *Moghania*. Sharply defined edges are present against forest in fluvial 'fire-shadow' zones.

Once a savannah/grassland community has been created in this way, its subsequent history may be determined chiefly by fire intensity and frequency. In the complete absence of fire, forest trees as well as savannah trees are sooner or later likely to be re-established either from seed stock in the soil or from seed dispersal by animals or wind. In time, with increasing tree cover, grasses are shaded out and the community reverts entirely to forest. According to Brock (2001), the fire-free interval required for woody tropical forest vegetation to establish on dry sites ranges from five to ten years. In the case of relatively intense fires, even longer periods between fires will be required for forest to re-establish over grassland or savannah.

For the Port Moresby-Caution Bay region, Eden (1974) and Gillison (1983) both consider the dominant fire frequency in grassland/savannah habitats in this area to be annual. However, fire can be initiated through natural as well as human agency, and it is not possible in the context of this landscape to distinguish the frequency of natural as against human ignition events. Lightning strikes in forest are unlikely to result in a spreading fire, due to the moisture content of the litter layer. By contrast, a lightning strike in grassland can be an effective means of ignition. Under this regime, re-establishment of forest communities seems unlikely to occur, even where human-induced ignition is infrequent.

Small savannah seedlings are also prone to destruction by grass fires. The frequency and intensity of firing required to prevent re-establishment of savannah tree species is not known with any precision. Paijmans (1976) intimated that relatively frequent and intense fires are needed to prevent eucalypt regeneration over open grassland. However, frequent lower intensity fires that destroy young seedlings may eventually deplete seed stock in the soil and lead to a more lasting absence of savannah trees in a grassland environment.

Hinterland Zone Animal Resources

The animal resources of the hinterland habitats have been heavily impacted by recent intensification of land use in the Caution Bay area. However, in 2007 local residents were still hunting regularly for wallabies, feral pigs, and cuscuses (Woxvold 2008).

From wider regional and historical records, we can reconstruct a strong dichotomy in the mammal fauna in the hinterland, with one suite of species found in savannah and grassland habitats, and another found in evergreen and deciduous forests (see Woxvold 2008: appendices 1 and 2). Native mammals of savannah and grassland include the Agile Wallaby (*Macropus agilis*, a grass-eating herbivore), the Short-Nosed Bandicoot (*Isoodon macrourus*, an omnivore), several small rats (*Rattus gestri* and *Melomys lutillus*) and a selection of insectivorous bats. Many of these species (or closely related forms) also occur widely in savannah habitats across northern Australia.

Riparian rainforest growing along watercourses, and patches of evergreen and deciduous forest growing in sheltered contexts, formerly supported a more diverse mammal fauna that included a different species of wallaby, the Grey Forest Wallaby (*Dorcopsis luctuosa*, a leaf-browsing species of dense forests), two or three species of bandicoot (*Echymipera kalubu*, *E. rufescens* and *Peroryctes broadbenti*, all omnivores), four medium-sized to large arboreal marsupials (Spotted Cuscus, *Spilocuscus maculatus*; Ground Cuscus, *Phalanger gymnotis*; Southern Lowland Cuscus, *P. intercastellanus*; and Striped Possum *Dactylopsila trivirgata*), one medium-sized carnivorous marsupial (New Guinea Quoll, *Dasyurus albopuntatus*), one large rat (White-Tailed Tree Rat, *Uromys* cf. *caudimaculatus*), a suite of smaller rats in the genera *Melomys*, *Paramelomys*, *Pogonomys* and *Rattus*, and a range of small bats including both blossom and fruit eaters and insectivorous forms (see Woxvold 2008: appendices 1 and 2). A third wallaby, the Dusky Pademelon (*Thylogale brunii*, a grass-eating herbivore) is primarily a species of forest-savannah/grassland ecotones, although it also occurs within large continuous tracts of closed evergreen forest, albeit as a rare element.

Scrub and thicket habitats probably act as daytime refuges for Agile Wallabies and Dusky Pademelons and they may also support dense populations of several species of bandicoots (most likely the Short-Nosed Bandicoot and Common Echymipera) and various small rodents. Like most other New Guinean mammals, bandicoots are nocturnal; they spend the day in temporary grass or leaf nests constructed anywhere that provides shelter, such as at the base of a tree or shrub, among rocks, or inside a hollow fallen log.

The majority of the larger arboreal species such as cuscuses, striped possums and the White-tailed Tree Rat are limited in their habitat use by access to suitable daytime refuges. All are strictly nocturnal animals and most spend the day asleep either inside cavities formed in the trunks of large mature trees, or within large clumps of epiphytes. These retreats are generally unavailable in scrub and thicket habitats that might otherwise provide adequate food resources for these species. One marsupial, the Ground Cuscus (*Phalanger gymnotis*), is unusual in that it shelters during the day on or below the ground, usually in spaces between rocks or among the roots of large rainforest trees. However, it is not a prolific digger and does not excavate burrows away from these contexts. It is not known to occur in true savannah or grassland habitats, but it has been recorded in riparian forests and patches of evergreen and deciduous forest growing within a regional savannah environment.

The alluvial landforms within the Caution Bay hinterland represent a prime foraging habitat for the Agile Wallaby on account of the relatively diverse grass communities and the slightly elevated soil moisture content that is presumably reflected in higher water content of the browse. Slightly higher soil moisture in these areas would also make them attractive targets for bandicoots and feral pigs, both of which dig through the topsoil in pursuit of invertebrate prey as well as tubers and corms. Several small rodent species may also attain peak local densities in this habitat, including the Grassland Melomys (*Melomys lutillus*) and Gestri's Rat (*Rattus gestri*). The former species constructs grass nests in dense tussocks, while the latter digs short burrows among the tussocks and also creates conspicuous runways that criss-cross the ground. Both species are dietary generalists, but grass-seed available in seasonal pulses is likely to not only form a significant part of their annual food budgets but to also drive their reproductive cycles.

One mammal species that may be restricted to alluvial landforms within the hinterland zone is the Common Water Rat, *Hydromys chrysogaster*. As mentioned earlier, this species probably also inhabits the mangrove communities. Indeed, given the relatively small areas and ephemeral nature of the freshwater habitat in the Caution Bay area, mangroves are more likely to represent the primary local habitat for this species, possibly with transient populations only in the hinterland.

A few native mammal species may have ranged widely across all of the hinterland habitats. One of these is the Short-Nosed Echidna (*Tachyglossus aculeatus*) that is able to occupy any habitat type provided it contains adequate numbers of ant and termite nests. This species can be active either by day or night; to rest it simply digs a temporary burrow among rocks or tree roots, or enters a fallen log.

Fruit bats of the genus *Pteropus* also probably range throughout the hinterland region, making use of seasonally available flowers and fruits including those growing in gardens. Fruit bats are congregatory species and they typically use tall trees along watercourses as ‘camps’ for rest and social activity. Small groups of a few tens of animals usually signify a temporary camp occupied during a foraging foray. Larger congregations typically form for specific purposes including courtship and mating, and for birthing and rearing of the young. Major roost sites for some species can contain tens to hundreds of thousands of individuals and are often situated in large tracts of mangrove or swamp forest where they are more-or-less protected against human predation. No major roost sites are known in the vicinity of Caution Bay.

Feral pigs today occur widely through the habitats of the hinterland and any patterning to their distribution is more likely a product of variable hunting pressure rather than of habitat preference. Elsewhere in southern New Guinea feral pigs occur at high densities in both closed lowland forests (evergreen and deciduous) and in savannah and grassland habitats (Hide 2003). Pigs are highly mobile omnivores. During the day small family groups usually shelter in thick scrub or shady gullies; they move out together after dark to favoured feeding areas. These may include swampy areas where the pigs root up large areas of soil in search of tubers and worms, patches of forest where they search for fallen fruit, and gardens where they can wreak havoc to most crops. One reason for the success of pigs as feral animals is their propensity to exploit a wide diversity of seasonally available food resources.

The reptile and amphibian fauna also contain species that are characteristic of each of the major habitat types (see Woxvold 2008: appendices 1 and 2). Native reptile species restricted to savannah and grassland habitats include a dragon lizard (*Lophognathus temporalis*), various small skinks (species of *Carlia*, *Cryptoblepharus* and *Sphenomorphus*) and a gecko (*Nactus* cf. *pelagicus*), the Carpet Python (*Morelia spilota*), and a small whip snake (*Demansia vestigiata*) (Woxvold 2008; see also Allison 2007; O’Shea 1996). Native frogs confined to wetland habitats within the savannah grassland mosaic include the Green Tree Frog (*Litoria caerulea*).

Closed evergreen and deciduous forests also support a number of restricted native species including a dragon lizard (*Hypilurus dilophus*), the Emerald Monitor (*Varanus prasinus*; this species is also found in the mangrove communities), the Ground Boa (*Candoia aspera*), the Emerald Python (*Morelia viridis*), the White-Lipped Python (*Leiopython albertisii*) and several arboreal back-fanged snakes (Green Tree Snake, *Dendrelaphis punctulat*a; Slatey Grey Snakes, *Stegonotus* spp.). Various small frogs are locally restricted to the closed forests, most notably members of the family Microhylidae that undergo direct development from eggs and thus occur in the absence of standing water.

Many more species of reptiles and amphibians are broadly distributed across the major habitats of the hinterland, including several additional pythons (the Scrub Python, *Morelia amethystina*; the Papuan Python, *Apodora papuana*), several species of a variety of highly venomous terrestrial front-fanged snakes (the Papuan Black, *Pseudechis papuana*; the Taipan, *Oxyuranus scutellatus*; the Death Adder, *Acanthophis laevis*), one or more arboreal back-fanged snakes (the Cat-Eyed Snake, *Boiga irregularis*), and the Blue-Tongued Skink (*Tiliqua gigas*). The White-Lipped Tree Frog (*Litoria infrafraenata*), the largest of the locally occurring native frogs, is a notable habitat generalist.

The resident bird fauna of the hinterland numbers around 150 species, with a further 50 or more species present as seasonal migrants. Sixty or more of these species are probably restricted to the closed forest habitats within the hinterland, although a significant proportion of these are also active within the mangrove forest communities. Several species are probably restricted to the grassland and savannah habitats, including various grass-seed eating birds such as finches that forage in conspicuous flocks. Many more species are widely distributed across the available habitat types, although many of these rely on patches of dense scrub and thicket and/or the ecotonal habitats along the margins of forest communities for shelter.

Wetland habitats within the hinterland are used as foraging areas by various kinds of birds including herons, egrets, bitterns and ducks. However, since none of these habitats are especially productive, no major feeding congregations are likely to occur.

Cassowaries and mound-building megapodes are two groups of birds of economic importance. Cassowaries are large flightless fruit-eating birds that primarily inhabit closed forests across New Guinea. They are solitary and territorial, and individual birds occupy large home ranges to ensure an adequate supply of fruit year round. Cassowaries are thought to play a critical role in forest ecosystem dynamics by dispersing the seeds of many rainforest plants, including those with large fruits that lack other agents of dispersal (Mack 1995; Mack and Wright 2005; Westcott *et al.* 2008).

The Southern Cassowary (*Casuarius casuarius*) is not currently found in the immediate Caution Bay hinterland, but its former occurrence can be confidently predicted. This species is sensitive to hunting and the harvesting of its eggs and populations have been suppressed across its range wherever exploitation exceeds moderate levels. Cassowaries breed in late winter or spring in the southern lowlands of New Guinea.

Megapodes are large, ground-foraging birds that are often exploited for meat and for their eggs. Two species are present in the southern lowlands of New Guinea, the Black-Billed Brush-Turkey (*Talegalla fuscirostris*) and Orange-Footed Scrubfowl (*Megapodius reinwardt*). Both may have formerly occurred in the hinterland of Caution Bay, most likely confined to patches of closed forest and in moister scrub and thicket communities.

Male megapodes construct and maintain large mounds of soil and leaf litter and also defend the mound against rival birds. Multiple females usually deposit eggs into a single mound where incubation is achieved by heat generated from decomposing vegetation. The young are independent from the moment of hatching.

Megapode eggs are large and contain a high proportion of nutritious yolk. Females of some species commonly produce more than their own body weight in egg mass within a single breeding season (Jones *et al.* 1995). Megapode mounds represent an important seasonal resource in many parts of PNG, and the eggs of an individual mound may be harvested over multiple years. Adult birds are also widely eaten. The mounds are also commonly raided for eggs by monitor lizards, bandicoots and feral pigs. Both species of megapode breed from September-February in the southern lowlands of New Guinea.

Although virtually all species of birds were consumed in at least some traditional Melanesian societies, certain groups such as pigeons are typically prized as game animals on account of their size. The Southern Crowned Pigeon (*Goura scheepmakeri*) is a terrestrial-foraging species found regionally in lowland closed forests. It is the world's largest pigeon and in many parts of PNG it is highly prized for its meat and plumes (Coates 1985; King and Nijboer 1994). Other large-bodied pigeons that would be expected to occur in the Caution Bay hinterland include the Torresian Imperial Pigeon (*Ducula spilorrhoa*) and various species of fruit dove (*Ptilinopus* spp.). Many of the pigeons forage across both open and closed habitat types, but a few are restricted to forest communities (Woxvold 2008: appendices 1 and 2).

The ephemeral waterways of the hinterland contain a restricted number of small native fishes and crustaceans (Hydrobiology 2008), a number of freshwater mollusc species, and potentially several resident freshwater turtle species. At least in recent times, the dry season biomass is low across all groups of animals that inhabit these waterways (Hydrobiology 2008).

Only four species of freshwater fishes were detected during the dry season in the hinterland watercourses of Caution Bay; one of these is a recently introduced fish (Tilapia, *Oreochromis mossambica*) (Hydrobiology 2008: table 3-3). Regionally, the freshwater fish fauna of small catchments along the south coast of PNG is comprised of predominantly amphidromous species. These species breed in the freshwater environment, probably cued by high flows, and the eggs are transported downstream into estuaries (see Hydrobiology 2008: figure 3-5 for schematic summary). Subsequently, juveniles migrate back upstream to freshwater. It is not clear whether or not this cycle can be completed in the Vaihua River itself, which appears to lack direct channelling into the upstream reaches. However, it is possible that the cycle is facilitated through the intermediate habitats of the flooded saltpans. Whatever the case, it is possible that in the wet season, the freshwater habitats of the hinterland waterways carry both higher fish species diversity and higher abundances.

The crustacean fauna of these systems is dominated by prawns of the genus *Macrobranchium* (Fruscher 1983); these can be locally abundant but they are small and delicate, and their remains are unlikely to survive in most archaeological contexts.

Five species of freshwater turtle are known to occur in the southern lowlands of PNG (Georges and Thomson 2010). All but one of these may occur in the Caution Bay catchment (see Woxvold 2008: appendices 1 and 2). The potential candidate species are all members of the family Chelidae, which includes both the long-necked turtles (*Chelodina* spp.) and several genera of short-necked turtles including *Emydura* and *Myuchelys*. The species of *Chelodina* and *Emydura* are essentially semi-aquatic animals that can cross large areas of forest or grassland to find suitable new aquatic habitats. Species in both genera are recorded in the Laloki River and it is likely that they either reside in the coastal catchments of Caution Bay or else disperse on occasion into this area. By contrast, the Soft-Shelled Turtle *Pelochlys bibroni* that is also recorded in the Laloki and Brown Rivers (Georges and Thomson 2010) is a fully aquatic species of freshwater habitats that would be unable to exist in the estuarine environment of the Vaihua River inlet and unable to colonize the hinterland habitats of Caution Bay from the north.

Molluscan taxa drawn from freshwater environments that are present in archaeological contexts at Caution Bay include the Violet Batissa (*Batissa violacea*) and small river snail gastropods (e.g., *Theodoxus fluviatilis*) (Lamprell and Healy 1998: 180-182; WoRMS Editorial Board 2014).

The Inshore Marine Zone

The Inshore Marine Zone includes all of the habitats out to and including the fringing reef. Mean water depths in this zone are typically less than 5m.

The tidal cycle in the Port Moresby region is semi-diurnal, with two high and low tides per day (CNS 2008a: 9). Mean spring tidal height in Caution Bay is less than 3m (i.e., +1.5m and -1.5m from mean spring sea level).

The coastline of Caution Bay is exposed to local surface waves generated during the southeast Trade winds which blow onshore through the winter months (Hemer *et al.* 2004; see 'Climate' section, above). By contrast, during the northwest monsoon winds are primarily offshore and result in little or no swell. In the southern part of Caution Bay, the severity of the waves is reduced by the presence of the fringing reef (CNS 2008a: 9).

Inshore Marine Zone Substrates and Habitats

Four distinct substrates and habitat types run more or less parallel to the shoreline as a series of discontinuous bands. From the shore outwards, these are:

- Submerged sand patches.
- Seagrass meadows.
- A *Sargassum* (brown algae) community.
- A fringing reef, situated <1km offshore.

The broad-scale distribution of sand patches, seagrass and fringing reef habitats is mapped in Figure 7.2 for the sea offshore of the archaeological study area.

The submerged sand patches are essentially devoid of plant or algal growth. They typically lie offshore of sandy beaches, providing a continuity of substrate that extends to the inner margin of the fringing reef.

Seagrass meadows grow at shallow depth in two main contexts in Caution Bay: 1) between the sand patches and the fringing reef; and 2) as an outer band, without protection of a fringing reef. No seagrass meadows are found outside the fringing reef (CNS 2008a).

Johnstone (1982) provided a detailed characterization of a local seagrass community in which four zones were recognized:

Zone 1 *Halodule uninervis*: A narrow-leaf phenotype of *H. uninervis* forms pure, but often sparse, stands located at shallower tidal height of the main seagrass meadow. This zone is found where the sandy substrate is relatively stable.

Zone 2a *Cymodocea rotundata*: This zone forms the upper fringe of the main seagrass bed. On coral reef flats it can be several hundreds of meters wide. The main associate of *C. rotundata* is *Halodule univervis* (wide- and narrow-leaf phenotypes), while *Syringodium isoetifolium, Halophila ovate, H. ovalis, Thalassia hemprichii* and *Enhalus acoroides* may also be present.

Zone 2b *Halophila ovate*, *Halophila ovalis*: In areas where sand substrates are unstable, the landward edge of the *C. rotundata* zone is replaced by stands of *H. ovate* and *H. ovalis*. Occasional *C. rotundata* make up the assemblage.

Zone 3 *Enhalus acoroides-Thalassia hemprichii*: This zone typically forms the bulk of the seagrass meadow, and at least one of the two dominant species is present. Other species are variably present, including *Halophila ovalis, Halodule uninervis* (wide-leaf phenotype) and, where the substrate is sandy rather than muddy, *Syringodium isoetifolium*. When *Enhalus* species are absent, *Cymodocea serrulata* can be moderately common.

Zone 4 *Halophila spinulosa*: This zone occurs at the greatest depth, located below the *Enhalus-Thalassia* zone. The community is distinctly open, and aside from *H. spinulosa*, there are only two other common associates (*C. serrulata* and wide-leaf *H. uninervis*). *Halophila ovalis* is less often present. All of these species are unlikely to occur together in any one location.

Thalassodendron ciliatum does not occur in any of the zones but forms monospecific stands on rocky or coral outcrops.

Seagrass communities are of ecological significance as nursery habitats for prawns, lobsters, crabs, turtles, dugongs and fish. They also serve to stabilize sandy substrate.

Within Caution Bay, macro-, coralline and turf algae are all present. The most commonly encountered algae are species of *Padina, Sargassum, Turbinaria, Caulerpa, Halimeda, Actinotrichia, Dictyota* and *Lyngbya* (CNS 2008a). Slimes formed by various blue-green algae (Cyanophyceae) are located on accreting mud banks (Johns 1982).

Prolific growth of the brown alga, *Sargassum* sp., currently occurs in a zone between the fringing reef and the seagrass beds (CNS 2008a). *Sargassum* is the dominant algal species in tropical latitudes (Womersley 1987), occurring wherever there is a stable substrate in relatively clear water with limited grazing pressure (Cribb 1990; Vuki and Price 1994). Macroalgal beds in shallow tropical waters can support high primary and secondary biotic production (Schaffelke *et al.* 1996) that may also be an effective indicator of increased nutrient inputs (Schaffelke and Klumpp 1998). The reef slope and crest are largely free of *Sargassum* growth.

The fringing reef at Caution Bay is predominantly made up of massive *Porites* corals with *Acropora* spp. present in greater diversity but lower cover (CNS 2008a: 30). *Porites* spp. accounted for between 7.7% and 87.5% of the hard coral cover at all Coffey Natural Systems sampling locations in 2007 (CNS 2008a: 30). Branching *Acropora* spp. coral was observed infrequently during the Coffey Natural Systems study.

In 2007, the major substrate type across all sampling sites was abiotic lifeforms such as dead coral, rubble and sand. To some extent this may reflect incomplete protection by the barrier reef from ocean swells or from wind-generated waves during storms and the dominant winter southeast Trade winds. However, it is probably also a result of the recent use of dynamite in fishing (CNS 2008a).

Inshore Marine Zone Animal Resources

Intertidal Rocky Shores

Caution Bay molluscan taxa commonly associated with intertidal rocky shore environments include mussels (Mytilidae), oysters (Ostreidae), Furrowed Clusterwinkle (*Planaxis sulcatus*), *Nerita* spp., species of top shells (*Trochus* spp.) and *Lunella cinerea* (Houbrick 1987; Poutiers 1998a, b).

Intertidal Sand-Mud Flats

Ark shells (e.g., *Anadara antiquata*), cockles (*Fragum unedo*) and tellins (Tellinidae) are shallow burrowers in clean to muddy sands (Poutiers 1998a: 255, 322).

Shallow Sandy Seafloor and Seagrass Beds

Anadara antiquata is a poor burrower and, although found in intertidal sand-mud flats, prefers sandy gravels and shallow lagoon bottoms. *Gafrarium* spp. also favour shallow, sandy habitats and seagrass meadows of the high intertidal zone (Tebano and Paulay 2000). The Strawberry Conch (*Conomurex luhuanus*) along with other strombid species (e.g., *Gibberulus gibberulus* and *Laevistrombus canarium*) reside in shallow waters, mainly in sandier areas within the seagrass beds (Coleman 2003; Poiner and Catterall 1988: 192). Bubble Shells (*Bulla ampulla*) occur in sheltered habitat areas characterized by sand or mud and seaweed (Malaquias and Reid 2008: 516).

Seagrass communities are important nursery habitats for prawns, lobsters, crabs, turtles, and many kinds of fish. They can also be important feeding sites for dugongs (*Dugong dugon*; Hudson 1977), although according to a recent study dugongs are 'rarely caught' in Caution Bay (CNS 2008b: table 2).

Based on wider regional studies (e.g., Honda *et al.* 2013; Unsworth *et al.* 2007), the sandy inshore and seagrass habitats would be expected to support a distinctive fish community made up of some resident species and others that forage in these areas but move to and from shelter within either the fringing reef or the mangroves. Among the more characteristic residents of these habitats are a variety of rays (Orders Myliobatiformes and Rajiformes) and boxfishes (Family Ostraciidae).

Estuaries, Mangroves and Upper Tidal Mudflats

Common taxa found in Caution Bay archaeological sites, inhabiting muddy bottoms of mangroves and tidal flats, include the Granular Ark (*Tegillarca granosa*), Common Geloina (*Polymesoda erosa*), Corrugate Lucine (*Austriella corrugata*) and Telescope Snail (*Telescopium telescopium*). Tree oysters (*Isognomon* spp.) live in dense colonies, attached to rocks or trees and other hard substrates in muddy estuaries and mangroves (Poutiers 1998a: 190).

Estuaries along the southern mainland coast of PNG harbour a distinctive fish community that includes families not well represented in reef or sandy inshore habitats (Munro 1967). These include the mullets (Family Mugilidae), hardyheads (Family Atherinidae), garfish (Family Hemirrhamphidae) and trevally or jacks (Family Carangidae). Many of these same species also occur in mangroves.

Coral Reef Flats

The jewel box shells (*Chama* spp.) and pearl oysters (*Pinctada* spp.) are commonly found attached to coral and rock reefs in the littoral and sublittoral zones. Giant-clam shells (Tridacnidae) and Commercial Top-Shells (*Tectus niloticus*) are obtained from clear, shallow waters of coral reefs. Relatively large conch shells (*Lambis* spp.) also inhabit reef flats and coral rubble bottoms of the intertidal and subtidal zones (Bellchambers *et al.* 2011; Poutiers 1998b: 467).

Present-day fish populations on the Caution Bay reef appear to be heavily impacted by over-fishing (CNS 2008a). Surveys in 2007 and 2008 found the larger reef fish typically targeted by fishermen (and occasionally, fisherwomen) to be rare, including snappers (Lutjanidae), emperors (Lethrinidae), groupers (Serranidae), and sharks. In contrast, reef-dependent species that rely upon the structural complexity of corals for refuge and protection remained common at most sampling sites. However, the majority of these are small fishes of the families Pomacentridae (damselfish), Chaetodontidae (coralfish, butterflyfish) and Acanthuridae (surgeonfish), typically with body lengths up to 15-20cm. Less common but still moderately common were Labridae (wrasses or tuskfish) and Acanthuridae (surgeonfish), among which larger body sizes are attained in some species.

Other useful comparative information on regional reef communities comes from a survey of marine resource use at Barakau village, 20km east of Port Moresby (Raga 2006). At this site, the reef has also been damaged by dynamite-fishing. Nevertheless, the most speciose group of fish appeared to be the groupers with 15 species, followed by cods and emperors with 10 species each, parrot fish and surgeon fish with seven species each, and trout and snappers with five species each.

The fringing reef in Caution Bay currently supports high densities of the sea urchin *Diadema* sp. (CNS 2008a). Population densities of this 'weedy' urchin species are typically controlled by predatory fish and octopus, and they are known to increase in numbers when overfishing causes a reduction in numbers of these predators (Steiner and Williams 2006). Overgrazing by *Diadema* sp. can hinder the rate of coral settlement and recovery after damage.

The Offshore Marine Zone

The offshore marine zone includes the lagoon located between the fringing reef and the outer barrier reef, or where the latter does not occur, then the shallow ocean between the fringing reef and the edge of the continental shelf. It also includes the pelagic zone beyond the barrier reef.

Offshore Marine Zone Substrates and Habitats

Seafloor depth in the zone between the fringing and barrier reefs averages 25m across the bay, but reaches 47m at the seaward margin (CNS 2008a: 7). The seafloor across much of the inter-reef lagoon is characterized 'mainly by terrigenous silt and clay sediments with evidence of epibenthic faunal activity in the form of mounds and burrows' (CNS 2008a: 7). In areas of deeper water, from 30m to 50m, the seafloor is predominately muddy and there is sparse visible biota. Closer to the coast, the fringing reef bottom sediments are characterized by coarser coral sands and coral rubble.

As noted above, Caution Bay contains a large number of offshore shoals and coral bommies that rise from the lagoon seafloor to within 5m of the surface (CNS 2008a). These structures are focal places for fishes and other marine organisms. Between the offshore shoals, the seafloor consists of fine sands.

Beyond the barrier reef, the sea floor drops away rapidly off the edge of the continental shelf. This pelagic zone is located within 15km of Caution Bay, which is exceptionally close by PNG standards.

Offshore Marine Zone Animal Resources

The deeper waters offer little in the way of animal resources other than individuals or shoals of fish that may be moving through this zone. The deeper water fish communities have not been surveyed at Caution Bay, either between the barrier reef and fringing reef, or in the pelagic zone.

Information on the fishes of pelagic waters beyond a barrier reef off the village of Barakau, 20km east of Port Moresby (Raga 2006), provides useful comparative data for Caution Bay. Pelagic fishes observed in this area included Chevron Barracuda (*Sphyraena genie*), Rainbow Runner (*Elagatis bipunnulata*), Spanish Mackerel (*Scomberomorus commersoni*) and a trevally (*Caranx* sp.). Fishermen (and more rarely fisherwomen) using trolling methods in this area reported mainly catching the following species: Bonito (*Katsuwonus pelamis*), Yellowfin Tuna (*Thunnus albacares*), Giant Barracuda (*Sphyraena barracuda*), Giant Trevally (*Caranx ignobilis*) and Rainbow Runner. Deep-sea catches include Long-Nosed Emperor (*Lethrinus elongatus*), Red Emperor (*Lutjanus sebae*), Red Snapper (*Lutjanus* sp.) and Coronation Trout (*Variola louti*).

Environmental History

Regional Scale Influences and Events

The late Quaternary period saw dramatic changes unfold along the southern coast of New Guinea, with major impacts observed not only in the distribution of land and water but also in the nature of the terrestrial environments (Chappell 2005; Hope 2007; Hope and Aplin 2005; Nix and Kalma 1972).

The contemporary arrangement of land and sea was broadly established across southern New Guinea as regional sea-level maxima were attained around 7,000 cal BP (Chappell 2005; Perry and Smithers 2011). One consequence was the re-establishment of water-flow between the Pacific and Indian Oceans through Torres Strait, thereby contributing to a thermal maximum for the Indo-Pacific Warm Pool (IPWP) between 6,800-5,500 cal BP (Gagan *et al.* 2004). Stronger gradients in sea surface temperature caused southward migration and likely widening of the Inter-Tropical Convergence Zone (ITCZ), strengthening convective uplift and resulting in intensification of the monsoon system (Prentice and Hope 2006; Reeves, *et al.* 2013a, 2013b; Shulmeister and Lees 1995). According to Shulmeister and Lees (1995), poleward heat flux was more prominent than west to east transfer of heat in the early to mid-Holocene, causing higher monsoonal rainfall but a reduction in inter-annual variability via weak Walker Circulation (see below). Regionally warmer and wetter conditions are confirmed for the mid-Holocene in numerous pollen records that document conversion of savannah to evergreen forests (e.g., Indonesia) or the expansion of existing humid rainforest patches out of glacial refugia (Hope and Aplin 2005; Hope *et al.* 2004; Kaars *et al.* 2000).

The second half of the Holocene saw climatic changes in southern New Guinea that reflect a more general global trend toward slightly cooler conditions. Among the various linked changes that occurred in the millennium centred *c.* 6,000 cal BP, the IPWP appears to have contracted (Gagan *et al.* 2004) and the ITCZ appears to have narrowed and moved equatorward, both probably resulting in a weakening of the monsoonal systems. By contrast, a likely increase in the Pacific Ocean pressure gradient would result in stronger winds, particularly in the westerlies and easterly Trade systems and a strengthening of east to west heat exchange (the Walker Circulation).

The Walker Circulation has an inbuilt regulatory mechanism expressed as the ENSO cycle. Perturbations in ENSO can be initiated by internal stochastic events and do not require the action of external drivers (Hastenrath 2012; Prentice and Hope 2006). However, the intensity of ENSO cycles, and the scale of any impacts on weather patterns, are determined by the strength of the Walker Circulation system.

ENSO cycles are a major determinant of contemporary inter-annual climatic variability in New Guinea (BoM 2015a; Prentice and Hope 2006). As described in an earlier section (see ‘Climate’, above), in the Port Moresby-Caution Bay region La Niña events bring increased rainfall that can lead to flooding and slope instability, while El Niño events typically involve prolonged droughts. Both kinds of events have a lower incidence of tropical cyclones than ENSO-neutral years in southeastern New Guinea (BoM 2015a).

Numerous regional studies have detected an apparent intensification of ENSO cycles in the Western Pacific region during the late Holocene. These include studies of vegetation history based on pollen (e.g., Prebble *et al.* 2010; Shulmeister and Lees 1995), studies of coral growth rates (e.g., Gagan *et al.* 2004), and studies of dune activity from dust deposits in northern Australian lakes (Lees 1992). Lees (1992) also inferred an overall drying trend from the mid-to-late Holocene in the north Australia record, interrupted by periods of increased precipitation from 3,500 to 2,800 BP, again from 2,100 to 1,600 BP, and over several brief intervals in the past 1,000 years. Rowe (2007, 2015) demonstrated an expansion of wetlands on several islands in Torres Strait at *c.* 2,500 cal BP and again after 1,000 cal BP.

Hope *et al.* (2004) concluded from a review of available evidence from the Australasian region that simple models of late Holocene cooling and drying relative to the early Holocene may be of little utility to explain observed landscape and vegetation responses. Instead, they urged attention to the role of extreme climatic events as potentially significant determinants of environmental change, and episodic disturbance by people as another potentially independent factor.

Rising sea levels through the terminal Pleistocene and early Holocene saw the widespread drowning of both coral reef systems and coastal mangrove communities throughout the Indo-Pacific region. As sea levels peaked, corals and mangrove plant species colonized the new coastlines and began to re-assemble their characteristic communities. Ideal conditions for coral reef growth are slowly rising sea levels, while mangroves are favoured by stable sea levels on accreting coastlines. Grindrod *et al.* (2002) and Hope *et al.* (2004) reviewed the regional histories of mangrove histories and concluded that this kind of plant community most faithfully reflects the interplay of relative sea level fluctuations, coastal physiography and local sediment budgets. This interplay is apparent around the New Guinea coastline.

Numerous geomorphic studies and pollen records have been developed to map the changing extent and composition of mangrove communities around the New Guinea coast, and to understand the response of coastal vegetation to coastal progradation and sea level change, including regional studies along the southwestern New Guinea coast and along the Fly-Digul platform (Ellison 2005; Woodroffe 2000) and at Caution Bay itself (Rowe *et al.* 2013; see below). In the more westerly sites, present-day estuarine locations document freshwater ecosystems at 9,600-8,700 cal BP, followed by a dominance of shallow water mangrove species (especially *Bruguiera*) until *c.* 2,500 cal BP, and then by deeper water mangrove species (especially *Rhizophora*) (Ellison 2005). These changes track a rise in relative sea level through the Holocene at rates that match local sediment accretion (Ellison 2005).

Along much of the south coast of PNG, the ranges of the Central Cordillera are fringed by an uplifted coastal plain of either marine or alluvial origin, although here it lacks the steep coastal margin and coral terraces seen in northern parts of PNG (Löffler 1977, 1982). These elevated plains have been emergent above sea level through much of the Quaternary and are narrowly incised by the various large rivers that emerge from the Central Cordillera. As a result, the mangrove communities of the southern coast of PNG, although substantial, never quite matched the scale of those that occurred in the northern lowlands.

Local Influences and Events in Southern New Guinea

A vegetation history spanning the past *c.* 4,500 years is available from Waigani Swamp, a wetland complex in the Laloki River catchment located ~ 25km northeast of Caution Bay (Osborne *et al.* 1993). Here peat formation commenced around 4,400 BP, within a swamp dominated by a species of *Melaleuca*. These conditions persisted until *c.* 2,500 BP, although water depth appears to have increased gradually through this period. From 2,500 to 1,200 BP, the swamp was subjected to more frequent inundation but nonetheless supported a swamp forest community in the vicinity of the coring location; peak water levels are indicated after 1,700 BP. Between *c.* 1,000 and 700 BP there was a fall in water levels, tree cover declined, and an herbaceous reed swamp developed in its place, with *Nymphoides*, Characeae and grasses dominant. Osborne *et al.* (1993) were unsure whether these changes in moisture availability were due to increases in precipitation or to decreases in temperature and evaporation.

A pollen record obtained from Caution Bay itself is available from cores taken across the mudflat series just seaward of the archaeological site of Bogi 1, as reported by Rowe *et al.* (2013). As described earlier, the Caution Bay area has a relatively narrow Littoral Plains Zone as a consequence of the local deformational structure of the coastal plain that results in the major outflow from the Owen Stanley Range being carried westward by the Laloki River. By contrast, the various drainages that egress directly into Caution Bay have relatively small catchments. One outcome of this unusual local topography is that the record of sedimentation in Caution Bay is in effect a local record, albeit mediated by the effects of longshore sediment drift.

Initially, following post-glacial sea level rise, the Caution Bay landscape featured a dynamic open coastline. Fine sediments brought into the bay from the various hinterland catchments were removed by long-shore drift under incident wave action, and wind blowing across the sandy shore resulted in the construction of beach-bordering sand dunes (David *et al.* 2012). The offshore outer barrier reef system, which today lies about 5-10km offshore of Caution Bay, is rooted on the sea floor at a depth of ~ 40m or so below current mean sea level. The barrier reef may contain the remains of older reef systems within its core; however, the contemporary growth phase would only be initiated after it was inundated by rising seas. Since coral growth typically cannot keep up with sea level rise, the early phases of growth of the reef most likely occurred at depth and would have had little if any effect on conditions at the coast. However, as growth along the crest of the barrier reef caught up with the new sea level high stand, the reef would have started to block deeper ocean swells. Reduced wave action on the shoreline would have allowed finer sediments to accumulate along the shoreline. Reduced wave action may also have led to the establishment and growth of the fringing reef that today lies no more than 1km offshore and creates an even more protected environment along the shoreline.

Around 2,000 cal BP, rapid siltation commenced within Caution Bay. This was coincident with an inferred regional fall in relative sea level (Lewis *et al.* 2013) and may be explained fully or in part by this factor. However, local siltation might also have occurred as a consequence of increased sediment input from the hinterland, perhaps due to clearing for gardens or increased burning. Whatever the cause, the siltation appears to have been accompanied by a seaward extension of the fringing reef. Pollen preserved in the earliest sediments of the investigated cores document the occurrence of a *Rhizophora* mangrove forest growing on a newly deposited expanse of tidal mud flats between *c.* 2,000 and 1,740 cal BP (Rowe *et al.* 2013). At this time, *Rhizophora* forest appears to have been established across the tidal profile, with a direct border onto the terrestrial habitats. Around 1,000 cal BP, *Avicennia* appears and presumably assumes its current position in shallower tidal water, with *Rhizophora* and its associates withdrawing to deeper water zones around the periphery of the mangrove belt (Rowe *et al.* 2013). Simultaneously (and perhaps also correlated with a further, slight fall in relative sea level), a supra-tidal mudflat expanse was created, thereby separating the mangrove belt from the terrestrial habitats. Chenopodiaceae pollen that occur from this time onwards are suggestive of a saltmarsh community that probably occupied the margins around, and perhaps patches within, an otherwise unvegetated supra-tidal mudflat.

The pollen record also documents changes in terrestrial vegetation communities through the past 2,000 years at Caution Bay. During the earliest period from *c.* 2000-1740 cal BP, the occurrence of *Ficus*, *Euodia* and

Kleinhovia indicate the presence of a relatively moist dune thicket ecosystem with emergent trees with lower-lying depressions occupied by *Pandanus*, swamp grasses and sedges, ferns and the aquatic herb *Nymphaea/Nymphoides*. The presence of *Pandanus* and *Nymphaea/Nymphoides* are particularly suggestive of intermittent freshwater-logging on alluvial plains at this time.

Beginning *c.* 1,740 cal BP, there is a decline in tree taxa such as *Celtis* and *Kleinhovia*, along with coincident increases in Fabaceae, *Desmodium* and *Scaevola*. These changes most likely indicate a decline in moist thickets and an expansion of scrub, most likely on the littoral beach ridges and dunes. Through the past 1,000 years an increase in lower-layer shrubs such as *Hibiscus* and Solanaceae, as well as ferns and the climber *Flagellaria*, all point to the presence of dense low scrub on the coastal dunes. An increase in the relative abundance of *Pandanus* after 1,000 cal BP is noted by Rowe *et al.* (2013) as a possible indication of greater human disturbance.

Pollen derived from hinterland plant communities appears to become more prominent after *c.* 1,300 cal BP. The hinterland pollen was initially dominated by *Barringtonia,* followed by *Casuarina*. Palm types and *Terminalia* are incorporated, particularly after 1,000 cal BP.

Barringtonia was noted by Heyligers (1965) as an element of *Planchonia-Adenanthera* Forest, a slightly deciduous community found on alluvial plains, outwash flats and foothills of the Coastal Hill Zone, and one of the lushest of the forest types in Caution Bay. However, *Barringtonia* occurs elsewhere in southern New Guinea as the dominant tree species of an open woodland community growing in seasonally flooded watercourses (Paijmans 1976; Ken Aplin, personal observation). *Casuarina* received no mention from Heyligers (1965), and it may not have been present in the Caution Bay area at the time of the CSIRO land systems surveys in 1962. Casuarinas are common pioneer and beach-front species. In the broader Port Moresby area they are more often found growing in an ecotonal community between forest and savannah (Gillison 1983). It is unclear under what contexts casuarinas once grew within or around Caution Bay.

Myrtaceae pollen is scarce throughout the Caution Bay record. Values for Poaceae are also relatively low except at the surface of one of the pollen cores. Little can be concluded regarding the extent of savannah communities through this period.

Microcharcoal counts through the Caution Bay pollen cores suggest that burning occurred within the catchment throughout the past 2,000 years. There is a small but consistent decline in microcharcoal counts after *c.* 1,400 cal BP, with a possible return to higher levels between 750 and 300 cal BP (Rowe *et al.* 2013).

Changes in near-shore habitats through the past 6,000 years presumably had profound impacts on the availability of littoral and marine resources, and these changes in turn would have influenced local subsistence practices. Archaeological molluscan remains analysed to date indicate that prior to *c.* 2,000 cal BP people obtained resources from a variety of intertidal habitats, but generally with few mangrove species represented (McNiven *et al.* 2012).

Identifying the precise nature and timing of changes in the marine resources of Caution Bay, and quantifying and understanding the nature of human responses to these changes are two of the major objectives of the reporting of the Caution Bay archaeological molluscan remains.

Historical and Contemporary Land Use

Terrestrial Environments

Caution Bay was extensively cleared of vegetation for agricultural and/or pastoral purposes in the early 20th Century. The following quote from Stuart (1970: 277) provides hints as to the earliest colonial phases of European modification of the landscape:

> A little way further on the road branches again, that going to the right running for about 12 miles across the grass plains to Lea Lea Village on the mouth of Mokeke Creek. On the plains is situated Fairfax cattle station which was once a sisal plantation. The plant, from which hemp is produced, grew well and for a time seemed to be a promising cash crop for Papua but prices fell and the plantation was abandoned in the early 1920s. Shortly after the Lea Lea turnoff, the main road divides once more, the right fork leading to the large marine villages of Porebada and Boera.

Fairfax cattle station operated from the 1920s until into the early 1980s, with the station itself located in the northwest portion of the study area.

A detailed description of regional land use was produced as part of the CSIRO land systems survey in 1962 (Scott 1965). At that time, the Coastal Hill Zone supported a combination of commercial cattle stations and small-scale shifting agriculture, carried out primarily for subsistence purposes but supplemented by some cash cropping. Hunting and gathering of marine resources were also reported. These practices continue today to a significant extent, although cash cropping has risen in economic importance.

Gardening

Traditional shifting agriculture was carried out by local Motu and Koita landowners. In order of importance, the main food crops were banana, taro, sweet potato, and sugar-cane. These were usually planted together inside a perimeter fence designed to exclude feral pigs. Coconuts were also an important source of food; these were planted in small groves on the sandy beach ridges, while gardens were more often located inland along narrow river levees or in favourable locations within the forest-savannah mosaic.

Garden size was mostly around one to two acres (Eden 1974) and garden placement generally reflected the location of settlements. At Caution Bay, most gardens probably were located close to the coastal villages, with more remote gardens situated inland in the Alluvial Plains and Coastal Plains Complexes of the Coastal Hill Zone (Scott 1965). Eden (1974) records a regional preference for gardening at the savannah-forest ecotone, due to enhanced soil fertility and the ease of planting in topsoil without the need to remove grass roots. However, in a later publication Eden (1993) reported that larger communal garden complexes were variably placed in forest and savannah, and stated that savannah locations were not only common but actually favourable for taro cultivation.

New gardens were established in the dry season (Dearden 1987; Eden 1993; Paijmans 1976). To create a new garden in forest, undergrowth was first cut by hand, then small trees were felled and larger trees either cut or ring-barked. This small-scale land clearance typically occurred from June to August. Cut debris typically was stacked around tree stumps and left to dry before being burnt in late October and November. Planting usually took place in December, generally using seeds retained from previous crops, usually followed immediately by fence construction. Weeding and repair of fences were constant, ongoing tasks through to the time of harvest.

Where gardens were created in grassland or savannah, grass cover was usually burnt or else cut prior to turning over the grass sward. Grass that was cut from one plot was typically laid down on another as surface mulch. This practice of mulching was commonplace for new gardens created in savannah habitat (Dearden 1987; Eden 1993; Paijmans 1976). The typical lifespan of gardens was three to four years (Eden 1974), followed by a fallow period under grassland or scrub that ranged from 5 to 15 years (Dearden 1987).

Following abandonment, gardens located in forested areas tend to revert to a mixed woody shrub community. The garden area is quickly overgrown by herbaceous communities of garden weeds, grasses and creepers, followed by fast-growing woody plants. The floristic composition of young regrowth depends on several factors including the soil seed bank, root stock survival and chance establishment after seed dispersal by wind or animals including birds and bats. Species of Euphorbiaceae are usually common in the early woody regrowth (Dearden 1987; Eden 1974), while Paijmans (1976) lists *Kleinhovia, Macaranga* and *Althoffi*a as also common in these contexts. In the absence of any continued gardening activity or burning, the vegetation gradually becomes more varied in composition, growth form and structure. Light-demanding shrubs and/or trees are gradually replaced by more shade-tolerant species, herbaceous climbers are replaced by woody climbers, and herbaceous ground cover is replaced by ferns, gingers and shade-loving herbs. The canopy layer of old secondary growth commonly features one or more species of *Cananga*, *Endospermum*, *Canarium*, *Euodia*, *Laportea* and *Sterculia*. Pandanus and palms increase in abundance over time, and bamboo may also be common (Paijmans 1976).

Gardens in grassland areas initially revert into mixed dense herbaceous and grass communities (Dearden 1987). Subsequent events depend largely on which grasses are involved in early colonization after abandonment, which in turn is influenced by the intensity of prior weeding as well as the degree of depletion of the soil, and whether or not the grasses are subsequently burnt. Some grasses such as *Imperata* species are more likely to sustain fires of sufficient intensity to destroy woody regrowth. If this process does not occur, regrowth tends to proceed as described for forest plots, with the result that grasses are soon shaded out.

Studies carried out elsewhere in the seasonal lowlands of PNG demonstrate generally higher soil fertility under forest communities than under adjoining eucalypt savannah (Gillison 1983), and with particularly elevated fertility in ecotonal contexts (Gillison 1983: 198-199). This probably reflects the greater diversity in the ecotones of plants capable of fixing atmospheric nitrogen, including representatives of Cycadaceae, Casuarinaceae, Eleagnaceae, Fabaceae, Myoporaceae, Rubiaceae and Ulmaceae. This may partly explain the documented preference in many parts of PNG for garden establishment along forest edges (Gillison 1983; see also Walker 1966), although other factors such as ease of access may also be influential.

Cash Cropping

Cash cropping was being introduced into the regional subsistence economy on a small scale with the assistance of Government agriculture officers at the time of the CSIRO land system surveys in the early 1960s. Some developments were run on a community basis, but the close proximity of Caution Bay to Port Moresby also allowed individuals or families to participate directly in cash crop economies (Dearden 1987; Scott 1965). The main local cash crops in the 1960s to 1980s were copra, coffee, cocoa and betel nut. Today betel nut is the most important cash crop throughout the region surrounding Port Moresby.

At the time of the Caution Bay archaeological fieldwork, only a small number of gardens were being tended across the study area (e.g., a banana patch at Konekaru), with a few more just outside the study area next to hamlets along the northward running coastal road to Papa village (Papa Lea Lea Road). Subsistence agricultural practices were evidently in decline compared with the level of activity of the recent past. In part, this trend may reflect the increased work opportunities associated with the development project itself and a greater reliance on store-bought foods.

Hunting

Animal exploitation during the early period of European settlement of Caution Bay most likely followed the regional pattern described by early European visitors to the Port Moresby region in the late 19th Century. These accounts mention the husbandry of pigs and also highlight the importance of wallaby hunting, particularly among the Koita, and the prominence of fishing, particularly among the Motu (Chalmers 1887: 14-15; Lawes 1879: 373, 375; Stone 1876: 47, 60; Turner 1878: 482, 487, 495; see also Allen 1977b, 1991; Oram 1977; Vasey 1982). Turner provided the most detailed account, observing that 'the food of the Motu consists principally of wallaby, fish, yams, bananas, cocoa-nuts, and sago' (Turner 1878: 481) and further remarked that in 'winter they live upon yams, bananas, and fish. In August the hunting season commences, and for two or three months they live almost entirely on the flesh of the wallaby' (Turner 1878: 481). Several of the early accounts make mention of widespread seasonal burning of savannah and grasslands to aid the hunting of wallabies (e.g., Romilly 1889: 164; Seligmann 1910: 87; Turner 1878: 471, 487; see discussion by McNiven *et al.* 2012: 144-145).

Hunting was still carried out by residents of the Caution Bay villages at the time of the scientific studies for the PNG liquefied natural gas plant environmental impact assessments (Woxvold 2008). Local residents identified the Agile Wallaby and the Southern Common Cuscus as the two most common target species. Hunting was carried out singly or in groups, with communal hunts usually carried out with the assistance of packs of dogs. As reported historically, communal wallaby hunts are often accompanied by the burning of grassland patches, especially of the dominant *Saccharum*-*Imperata* and *Imperata*-*Themeda australis* plant communities. Burning has the function of flushing out the game, but may also be undertaken in the knowledge that it promotes new growth preferred by grazing animals and also inhibits the regrowth of woody vegetation, thereby maintaining the open landscapes preferred by wallabies. Large-scale communal hunts are no longer as common as they were in the recent past, but small-scale hunts of this nature were witnessed on two separate occasions in late 2009 and early 2010 by archaeologists conducting the excavations at Caution Bay (see McNiven *et al.* 2012: 144-145; Figure 5.14); both instances involved the setting of substantial grass fires.

Other Terrestrial Resources

At the time of the scientific studies for the PNG liquefied gas plant environmental impact assessments, building materials and firewood were regularly harvested from the mangrove forests by local Motu and Koita communities, especially along their margins where access is possible by canoe (CNS 2008a). The extent of timber utilization from the hinterland was not documented, nor was information obtained on the utilization of non-timber forest products from the savannah or forest habitats.

Marine Environment

The marine environment of Caution Bay was still heavily exploited by local peoples at the time of the scientific studies for the PNG liquefied gas plant environmental impact assessments (CNS 2008b). During the field studies, local people (almost always men) were regularly observed to be fishing in the Vaihua River estuary using gill nets and spears, typically from small canoes, while a number of larger boats and canoes were observed offshore in Caution Bay. Most fishing in shallower water is done with hand-held bottom lines, use of nets or spearing at night with torches. In deeper water, people use a mask and spear gun, as well as long-line trolling techniques. People also reported collecting sea cucumbers from the sandy inshore environment, mud crabs and shellfish from the mudflats, lobsters, shellfish and urchins from the fringing reef, and octopus and squid from unspecified habitats (CNS 2008b: table 2). Most of these resources were harvested for local consumption and for sale at various afternoon markets in Port Moresby.

Discussions held between Coffey Natural Systems staff and local residents indicated that dynamite fishing has occurred in Caution Bay in recent times. However, no fresh evidence of dynamite fishing was observed during the marine field survey by Coffey Natural Systems. Coral rubble was observed to be covered in algal or bacterial films, indicating that some time had elapsed since any dynamite fishing (CNS 2009: 36).

Fewer fishing vessels and canoes were observed in the vicinity of offshore islands. However, one group of around 40 people was observed in 2007 on Idihi Island, where they were spearing and netting for sharks and reef fish, which they intended to transport to local villages for sale.

Interviews with local residents produced a list of 57 fish species from 21 families that could be caught in Caution Bay in relatively shallow waters, including the littoral lagoon inside the fringing reef, over or along the outer margin of the fringing reef, or over coral bommies within the deeper waters of the bay (CNS 2008b: table 2). Special mention was made of Red Emperor (*Lutjanus sebae*), which is not only commonly taken but also attracts a high sale price at markets. This species was said to be most often taken in deeper waters (~ 40m depth). People also identified nine pelagic fish species, including several kinds of tuna and mackerel that can be caught in deeper water around the outer barrier reef. Only two species were said to be caught exclusively within the estuarine environment of the Vaihua River inlet: Barramundi (*Lates calcarifer*) and Black Bass (*Lutjanus goldei*). Pelagic species were targeted with long line fishing.

Turtles were said to be caught only occasionally (around one per month), with mask and spear gun.

Concluding Comments

Archaeological sites of the Caution Bay study area are strategically located on or near a major estuarine system, which in the past would also have included extensive sandy beaches open to a sheltered lagoon bounded by a substantial offshore fringing coral reef. Over the past few thousand years, the open sandy shoreline was replaced with a closed mangrove-bounded one in the vicinity of the Vaihua River mouth, marking a change in the littoral and shallow marine resource composition and relative abundance. Regionally significant grassland covering the plains of the study area testifies to long-term human modification of the hinterland, including forest clearing for gardening and the use of fire in wallaby hunting. In short, the study area consists of, and is in close proximity to, rich habitats that for many thousands of years would have supported abundant populations of terrestrial and marine mammals, reptiles, birds, fish, crustaceans and shellfish. While other parts of Caution Bay also contain similar potential resources, only one other locality, Lea Lea Inlet in central Caution Bay, also has a major estuarine system, and this area was undoubtedly a focus for human occupation in the past, as it is in the present. A major difference, however, between the lower Lea Lea and the Vaihua drainages is the preponderance of low-lying swampland associated with the former, while grassland and savannah plain above flood level surround the latter, suggesting that prior to the appearance of the mangroves, human settlements in the study area would not only have had access to a varied set of ecozones with abundant plant and animal resources, but also extensive land suitable for gardening.