Introduction: island origins

Islands in different parts of the world often show similarities in origin although conversely, islands that appear superficially similar may sometimes have quite different origins. Commonalities of origin and physical development occur mostly among the community of ‘oceanic islands’, those islands that originated within the ocean basins (Nunn 1994). Older ‘continental islands’ are parts of the continents that have become islands through the uneven submergence of continental margins.

Most oceanic islands develop either along convergent plate boundaries or in intraplate (midplate) locations. Convergent plate boundaries are places where one slab (or ‘plate’) of oceanic crust (or ‘lithosphere’) is thrust beneath another. The downgoing plate is eventually pushed so far into the Earth that it melts, producing magma that sometimes finds its way back to the ocean floor where it erupts and may produce a volcanic island. Intraplate locations (‘hotspots’) are sites where the Earth’s crust is uncommonly thin and where liquid rock from the underlying asthenosphere may force its way to the surface to form a volcanic island.

Origins cannot always be readily determined from examination of modern, above-sea islands. Often, the key to an island’s origin lies buried deep beneath a thick cover of younger rocks, sometimes far below sea level, so the use of models of island genesis is common. For example, many atoll islands (islands formed on ring or atoll reefs) are made solely from superficial material that accumulated within the past few thousand years yet rest on ancient coral reef that, in turn, rises upwards from the underwater flanks of long-submerged volcanic islands; it is from the geochemical character of these volcanic rocks that we can learn about the ancient origins of particular atolls.

This section discusses the origins of islands by appearance and composition, beginning with nascent ocean-floor islands – from which all oceanic islands develop – through mature above-sea oceanic islands and older sunken islands. These are not primarily age distinctions but developmental stages that may not be attained by every oceanic island.

Young under-sea oceanic islands

All oceanic islands form as a result of volcanic activity on the deep ocean floor. Much ocean-floor volcanism is non-threatening and undramatic, often associated with upwelling of magma
(liquid rock) along a fissure that has extended downwards to tap an underground magma source. As the early eruptions continue and the amount of lava produced increases, so parts of the fissure become blocked, and eruptions become concentrated at particular points. It is these point eruptions that then allow the growth of small volcanic edifices which may one day form giant oceanic islands.

The weight of the ocean water overlying eruptions on the ocean floor renders these as non-explosive events. The principal material produced is pillow lava, so called because the magma is forced out of the volcano in discrete blobs, the outside of which immediately solidifies upon coming into contact with cold ocean water. The inside remains liquid for much longer while the blob rolls down the flank of the volcano, coming to rest at its foot and forming one of many ‘pillows’.

Yet, as an undersea volcano grows upwards, its crestal vent may eventually reach a point about 600 m beneath the ocean surface where there is no longer sufficient overlying water to suppress explosive eruptions. As the volcano grows above this level and into shallower water, eruptions become explosive – and spectacularly visible above the ocean surface (see Figure 3.1). One reason why many shallow-water eruptions are explosive has to do with the reaction between liquid rock (heated perhaps to 1,200°C), and cold ocean water, which leads to the production of fragmental volcanic material. These ‘volcaniclastics’ commonly drape the core (made from pillow lavas and intrusive igneous rocks) of undersea volcanic islands, but may also float to the ocean surface to form floating pumice mats, even an island.

![Figure 3.1 January 2005: An eruption of the Kavachi Volcano, located just below the ocean surface in the Solomon Islands. Source: © Simon Albert. Reproduced with permission.](image-url)
Islands made from newly-erupted volcaniclastic material may disappear through wave erosion once the eruption ends. Such ‘jack-in-the-box’ islands appear and disappear regularly in parts of the Southwest Pacific, such as Solomon Islands and Tonga, as well as in the Mediterranean Sea where Graham Island (Ferdinandea) appeared above the ocean surface southwest of Sicily, Italy, for six months in 1831–1832. For such an island to persist above the ocean surface, as has Surtsey off the south coast of Iceland in the North Atlantic, it is necessary for the eruptive vent(s) to be cut off from ocean water so that lavas will be produced instead of fragmental material (see Figure 3.2).

**Mature above-sea oceanic islands**

A newly-emerged volcanic island will commonly betray its origin, although various processes soon conspire to begin to disguise this. Denudation – the physical wearing away of the land – can erase the distinctive form of a volcanic island, even to the extent of reversing the original topography. Successive drowning and emergence associated with sea-level changes or long-term tectonic movements can also help disguise the origin of an oceanic island.

In the coral seas, generally those where ocean-surface waters remain between 20–27°C all year, the growth of coral reef around, sometimes even over, a subsiding volcanic island can transform it into an atoll island, one where the presence of a largely-submerged island edifice is manifested only by a ring of coral reef. Should an atoll island emerge as a result of experiencing uplift, it will then appear as a high limestone island (see Figure 3.3).

Such transformations are relatively common in the most tectonically-active areas of the ocean basins, particularly near convergent plate boundaries. The island of Jamaica in the Caribbean is an oceanic island, despite being unusually large (11,500 km²). Slow steady sinking of Jamaica beginning around 55 million years ago led to deposition of the ‘Yellow Limestone’ around its ancient volcanic core. The Yellow Limestone was overlain by the coral-reef dominated ‘White Limestone’ as subsidence continued, the entire island being submerged 40–25 million years ago. As a result of uplift associated with nearby plate convergence, the island subsequently re-emerged (Robinson 1994).

Most above-sea oceanic islands will begin to subside once volcanic activity ceases. Subsidence may occur because the island is being moved on an ocean plate from an area of shallower ocean (in which volcanic activity is taking place) to an area of deeper ocean (where it is not). Thus islands that move away from a hotspot generally become both smaller in area and lower in altitude, as their bases are carried into deeper water. The northwestern islands in the Hawai‘i group, for example, are mostly atolls or low volcanic islands that were perhaps once as large as the islands of Hawai‘i (the ‘Big Island’) and O‘ahu in the southeast of the group where the hotspot is located (see Figure 3.4).

**Ancient continental islands**

Islands of continental origin are generally larger and almost always older than oceanic islands. They may rise from continental shelves, as do the islands of Sardinia (Italy) and Tasmania (Australia), or from isolated pieces of continental lithosphere that have become detached from the parent ones, such as Madagascar and New Caledonia. The origins of these islands are generally as diverse and as complex as the continents themselves. Many well-studied structural alignments on continents are also exposed on offshore islands. For example, ancient Mediterranean islands (such as Minorca, Spain) appeared above the ocean surface at the same time and for the same
Figure 3.2 Diagrammatic history of the 1963–1967 eruptions of the Surtsey volcanoes.

Source: Nunn (1994), used with permission. © Patrick Nunn.

A – The earliest eruptions visible above the ocean surface were explosive owing to mixing of ocean water and magma.

B – Pyroclastic and ash eruptions from the main eruptive centre of Surtur I built a cone of unconsolidated volcanic fragments.

C – Eruptions from Surtur I ceased and a new eruptive centre (Surtur II) came into being. Since the ocean still had access to this centre, mixing with the upwelling magma occurred and eruptions continued to be of an explosive character, resulting in the accumulation of unconsolidated fragmental material easily eroded by the ocean.

D – Finally, the Surtur II centre became isolated from the sea and lava eruptions replaced those of pyroclastic materials. Lavas armoured the surface of the existing cone, rendering it significantly less vulnerable to marine erosion.

E – Eruptions renewed in the Surtur I area and lavas began to cover most parts of Surtsey. Lavas extruded on land that entered the sea gave rise to steam clouds. No explosive activity occurred because the surface of the lavas was already cooled.
reasons as the Alps, while the island of Trinidad exhibits the same structures as the adjacent parts of northern South America.

Some continental islands that subsequently found themselves close to unusually active convergent plate boundaries have become draped with upthrust pieces of the ocean floor called ophiolites. Well-studied island ophiolites are the Troodos Massif of Cyprus (Robertson 2002) and much of the main island (La Grande Terre) of New Caledonia (Gautier et al. 2016).

Some continental islands show signs of having been islands – and therefore subject to the same processes as older oceanic islands – for a considerable time. Only when Australia collided with the Banda Arc about three million years ago did the island of Timor begin emerging, a process that can be calibrated by the staircases of fossil coral reefs found along its coasts (Chappell and Veeh 1978).
Island landscapes

Like other landscapes, island landscapes vary in character primarily because of geology and climate. Amongst the principal geological controls are age, rock type (lithology), structure and tectonic history. Traditionally the most important climate controls on landscape were regarded as temperature and precipitation but, as geomorphic studies of islands have increasingly shown, climate history, particularly climate extremes, has also had profound influences on the character of modern island landscapes (Huggett 1991). Half a century ago, most scientists took a simple and uniform view of climate and discounted its past variations when trying to explain the evolution of particular island landscapes; whereas today, the evidence of past climates is widespread, ranging from former glaciation (such as u-shaped valleys) on islands like Arran in Scotland (MacDonald and Herriot 1983) to glacial-period wetness on tropical Hawai’i Island (Sheldon 2006). Yet, it is the variations attributable to lithology and evolutionary complexity that are most visible in many modern island landscapes, for which reason they form the basis of the discussion in this section.
Volcanic island landscapes

The nature of landscapes of active volcanoes varies, depending on that of the eruptive materials. Island volcanoes built solely from viscous lava often form dome-shaped edifices (cumulodomes) while those built from both lavas and fragmental material (stratovolcanoes) are usually higher and have steeper, characteristically concave, flanks. The volcanoes on the Caribbean island of Montserrat, that include the Soufrière Hills Volcano which erupted spectacularly in 1997, are stratovolcanoes, as are most of the active volcanoes in the Philippines including the highly-active Mayon on Luzon Island. Mt Egmont on the North Island of New Zealand is a mixture, its base being domed and representing an earlier phase of eruption to that involving mostly fragmental material which built the stratovolcano above. The largest volcanoes on Earth commonly form oceanic islands, such as those of the Hawai’i island chain, and are known as shield volcanoes, from the shape of the edifice they form, built largely from basalt lava.

Near the end of the active life of an island volcano, a caldera may form, either from explosions tearing out the heart of the old volcano or a collapse of the summit into an emptied magma chamber below. The landscape of the island of Nisyros (Aegean Sea) is dominated by a 15 km² caldera. On Lihir (Niolam) Island in Papua New Guinea, the formation of the Luise Caldera exposed a huge gold deposit (Corbett et al. 2001).

Once a volcano ceases activity, its form changes. Around symmetrical volcanoes, a radial drainage pattern will normally develop and, through time (as some streams are ‘captured’ by their neighbours), relict pieces of the flanks of the original volcano (planezes) will be isolated from erosion and may persist for much longer than the rest; planezes on the island of St Helena (South Atlantic), that last erupted some seven million years ago, are used as pastures on this otherwise deeply-eroded volcanic island. Most oceanic volcanoes subside when activity wanes or ceases, resulting in drowning of island coasts and the formation of bays where there were once valleys; stellate (star-shaped) islands like Ono (southern Fiji) may form (Nunn 1994).

Although an island comprising one or more extinct volcanoes may no longer pose a threat to its inhabitants from eruption, the steep-sided character of some oceanic volcanoes means that they are also notoriously unstable. The Hawai’i island chain, for example, is one of the steepest-sided structures on the Earth’s surface and has experienced periodic catastrophic flank collapses. One of these, perhaps around 105,000 years ago, may have created a wave more than 300 m high that washed back over the Hawaiian islands of Lana’i and Moloka’i, leaving behind gravels containing innumerable coral fragments (Moore et al. 1994). The same wave may have crossed the Pacific, driving up on every coast it encountered (Young and Bryant 1992).

Collapse of volcanic island flanks can occur with both active and extinct volcanoes. For example, the high volcanic islands of the Canary Islands have experienced enormous flank collapses many times in the past, some of which may have been caused only by gravity, others of which may have been triggered by the intrusion of magma deep within the volcanic edifice causing its flank to bulge and eventually collapse (Carracedo 1994). Flank collapses of island edifices in the Pacific have caused abrupt disappearances of entire islands (Nunn 2009).

Limestone island landscapes

Limestone is permeable, meaning that the surface landscapes of limestone islands are comparatively slow to evolve and may continue to represent the form of the island when it emerged above the ocean surface long after this event occurred. An example is the island of Niue (South Pacific), a coral atoll before it began emerging about 600,000 years ago. Niue now lies 70 m above the ocean surface; yet, the former lagoon and the former ring reef (named the Mutalau
Reef) are clearly visible in the modern landscape (Nunn and Britton 2004). The fringes of emerging limestone islands in warmer ocean-surface waters are often marked by staircases of fossil coral reefs; those on the island of Choiseul (Solomon Islands) extend 800 m above sea level (Stoddart 1969), while those on Halmahera (Indonesia) extend to 1,000 m (Hall et al. 1988).

The surfaces of many limestone islands are low relief; areas of lower ground (sinkholes or dolines) mark the places into which surface water is concentrated before moving down below the surface. In certain limestones, funnel-like sinkholes may develop close together and extend downwards several metres, giving rise to particular types of karst landscape, such as the cockpit country of Jamaica (Fleurant et al. 2008). Long before humans arrived, the remote limestone island of Nauru (central Pacific) was home to millions of seabirds whose phosphate-rich excrement filled the sinkholes. Mining of Nauru for phosphate during the 20th century has re-exposed the original karst (pit-and-pinnacle) landscape (Weeramantry 1992; see Figure 3.5).

The subterranean parts of limestone islands may change more rapidly than their surfaces. Rainwater percolates down from the ground surface and forms a freshwater lens that rests on top of limestone saturated with seawater. The unsaturated (vadose) zone above the freshwater lens is commonly riddled with cracks along which water trickles downwards. Sometimes, the cracks grow into narrow elongate and steeply-plunging caves: the ‘blue holes’ of the Bahamas and Caicos islands are vadose-zone caves formed during the last Ice Age and drowned by subsequent sea-level rise (Mylroie et al. 1995).

Within limestone islands, the surface of the freshwater (Ghyben–Herzberg) lens – the water table – is commonly dome-shaped, meaning that water which reaches it through the vadose zone usually then trickles through the limestone at an angle. The concentration of water flow

Figure 3.5 Contemporary pit-and-pinnacle landscape on Nauru island, west Pacific, being created by phosphate extraction.

down the dome of limestone-island water tables means that these are places where erosion (through solution and roof collapse) of the limestone is concentrated. Large water-table (or epiphreatic) caves often form in such places, leading downslope from the centre of an island to its coast, typically with a river, representing water flowing at the surface of the water table, running through it. Tatuba Cave in the interior of Viti Levu Island (Fiji) comprises a lower active part containing a river and several dry caves above, a result of the area’s uplift (Nunn 1998). Similar emerged caves are found along the coast of Isla de Mona (Puerto Rico) where most have developed along the contact between the principal reef-limestone/dolomite contact. This is an example of a geological structure influencing processes of cave formation (Frank et al. 1998).

Sometimes, miniature archipelagoes are created when karst landscapes are drowned, as in the case of southern Vava’u Island (Tonga) and Phang Nga Bay on the Krabi coast of Thailand (Nunn 1998, Harper 1999).

About 66 per cent of the continental Caribbean island of Cuba (111,000 km²) is covered by limestone and its landscape reflects this lithology, its great age, and its tropical climate (Itturralde-Vinent 1997). Most tobacco fields in Pinar del Río province in Cuba are in areas dominated by collapsed limestone separated by isolated remnants of the original surface, termed mogotes (residual limestone hills).

Composite island landscapes

Many islands cannot be readily classified as either volcanic and limestone. Many such composite islands have distinctive landscapes, at least in places, on account of their varied lithologies.

Larger islands of this kind, sometimes of continental origin, typically have an older core surrounded by rocks of younger age, often formed only after the landmass became an island. Typical of these is Jamaica (discussed above), Lesbos in the Aegean, and New Guinea, many fringing parts of which are formed by emerged coral reefs (Löfler 1977). In a reverse of this situation, the sedimentary core of the Shetland Islands (Scotland) that dates back to the Cambrian Era (590–500 million years ago), has become fringed by younger (Tertiary) lavas and intrusive igneous rocks (Stoker et al. 1993).

Among the smaller composite islands in ocean basins are the makatea islands that comprise a volcanic centre fringed by uplands made of emerged coral reefs; several examples are found in the southern Cook Islands of the Central Pacific (Nunn 1994, Stoddard et al. 1985).

Simple island landscapes

There are many, usually smaller islands that have simple landscapes on account of their comparatively homogenous composition. Such islands can be divided into young coral islands, which owe their existence largely to the growth of living reef, and others, typically those formed from detrital material introduced to nearshore areas by large rivers. Other such islands include ice islands and islands made from floating vegetation and/or pumice which may have been important in the dispersal of certain organisms from island to island, as well as lake and river islands discussed below (Stehli and Webb 1985, Van Duzer 2004).

(a) Young coral island landscapes

Islands exist on many broad coral reef flats and are composed primarily of reef detritus driven onto them by large (storm) waves and then concentrated in particular areas by wave action. On Funafuti Atoll (Tuvalu, central Pacific), a storm surge associated with Tropical Cyclone Bebe in
October 1972 led to the creation of a ‘rubble bank’ along the edge of the reef off the island’s east coast. Over the next few years, this rubble bank was moved slowly landward by wave action and became incorporated into the main island (Baines and McLean 1976). Analysis of the geology of other reef islands in Tuvalu show that they formed from the successive accretion and distribution of rubble banks of varying grade and size. On smaller reef platforms, the central lagoon-depression enclosed by these islands can eventually become infilled with reef detritus (McLean and Hosking 1991).

Newly formed coral islands of this kind are known as cays and are transient islands that often migrate across reef flats, and even are sometimes removed from them in their entirety. Sometimes, cays persist long enough for conglomerates (such as beachrock) to form just beneath their surfaces, and these help armour the cays and protect them from erosion; well-armoured cays that have persisted for centuries rather than years are known as motu. Most inhabited coral islands in countries like Kiribati and the Marshall Islands in the western Pacific are motu, and research has focused increasingly on their structure and how it might be influenced by sea-level rise (Nunn 1994, Dickinson 1999).

**(b) Non-coral island landscapes**

Denudation of continents and larger islands is manifested by the suspended sediment load of large rivers. When these rivers reach the sea, much of this sediment is deposited on the ocean floor which may then shoal to produce islands in places. At a later stage these islands often become incorporated into the mainland as they are subsumed by the prograding shoreline of the river delta.

In some places, such river (or estuarine) islands may become colonised by dense mangrove forests that stabilise them and help them endure. While not always desirable places for humans to live, mangrove islands are places where other organisms often thrive, and the destruction of such habitats is frequently lamented. Some of the 54 islands in the Sundarbans, the 10,000 km² mangrove forest at the mouth of the Brahmaputra-Meghna-Ganges in India and Bangladesh, are the objects of conflict between local inhabitants and conservationists (Ghosh 2015). Owing to their isolation yet relative proximity to the mainland, such islands may also be important places of refuge or retreat; the 6th-century Irish saint Senan founded a succession of monasteries on river-mouth islands, including one on Scattery Island in the Shannon Estuary.

**Controls on long-term environmental evolution of islands**

The island environments that we see today manifest the subtle interplay of nature and humans and it is consequently difficult to generalise about their long-term evolution. Yet, understanding environmental evolution is a necessary precondition to suitable and successful environmental management, increasingly a priority on many islands (Nunn 2004). The four critical controls on long-term environmental evolution of most islands are geology, climate (including changes in sea level), and extreme or rapid events. For those islands that have been inhabited by people for a significant length of time, pre-modern human impacts are often also a significant contributor to environmental development. Each of these four distinct controls is discussed separately below.

**(a) Geological controls**

The key element in understanding the evolution of island environments is time, specifically how much has elapsed since that island appeared. Geological history can provide an answer to
that, and also to the various earth–surface processes that have moulded island environments. For example, many island environments have been affected by volcanism, a few have been pushed upwards from beneath the ocean without a hint of volcanic activity, while others have alternated between periods in which each of these processes dominated. For instance, a former volcanic island may sink beneath the ocean surface, becomes covered with reef limestone, and then emerges: the island of Vava’u (Tonga, South Pacific) is composed of emerged reef limestone that covers an ancient caldera (Cunningham and Anscombe 1985).

Many volcanic rocks are easily moulded by natural denudational processes – the moonscape-like surface of Iceland is an example – whereas most limestones are more resistant and, on account of their permeability, comparatively unaffected by processes of surface denudation. Most volcanic islands in Samoa (South Pacific) have deep-cut valleys, a consequence of the low-resistant lavas from which many formed. The massive peridotites (olivine-rich igneous rocks) that cover 30 per cent of the main island (La Grande Terre) in New Caledonia have produced ultrabasic (very low silica) soils containing elements that are toxic to many plants (Gautier et al. 2016).

The geological structure of some islands exercises the dominant control on their landscapes and the ways they have evolved. The island of Iceland (North Atlantic) is one of the very few places on the Earth’s surface where a mid-ocean ridge (divergent plate boundary) emerges above the ocean surface, something manifested by a 150-km wide rift valley on the flanks of which there is considerable volcanic activity (Bott 1985). Ancient fold belts around the eastern Mediterranean margins extend onto islands offshore; for example, the islands of Crete and Rhodes are parts of the Hellenic Arc that is exposed conspicuously in mainland Greece (Barka and Reilinger 1997).

Many islands, particularly oceanic islands, lie in tectonically-active locations, and their environments manifest the long-term effects of tectonic processes. Owing to their location in a compressive tectonic zone associated with plate convergence, Miocene coral reefs on the large island of New Guinea emerged and became covered with impermeable volcanic cap rocks, creating hydrocarbon reserves (Hill et al. 1996). On a smaller scale, the island of Moala in southeast Fiji is bisected by a rift valley that has opened progressively as the island has drifted up a flexure in the ocean floor formed as a result of nearby plate convergence (Nunn 1995). The removal of Last-Glacial ice cover from some islands has resulted in their emergence, marked in cooler ocean waters by staircases of ‘raised beaches’, as are common on islands such as Lasqueti Island off the coast of British Columbia, western Canada (Hutchinson et al. 2004).

(b) Climate and sea-level controls

While geology may account for variations in the character of island environments, it is climate that largely drives the processes by which much of that change is accomplished. Weathering of islands in hot climates involves different processes – at commonly faster rates – than in colder climates. High levels of mean annual precipitation, especially when that is concentrated seasonally and/or in storms, generally result in faster and more profound changes in the environments than occur in all-year drier climates. For example, ground-surface lowering is 3–4 mm/year in the wet New Guinea highlands (Pickup et al. 1980) but only 0.04–0.19 mm/year in the Hawaiian Islands (Li 1988), the latter representative of most islands.

The oscillating temperatures of the last 10 million years, particularly during the Quaternary (last two million years), caused the Earth’s climate to swing between cool ice ages (glacials) and warm interglacials, such as that (the Holocene) in which we live. Changing temperatures forced vegetation zones to shift, and with them those organisms that could not adapt to the changed climate. Although the effects of these climate changes on certain islands have been somewhat
offset by the dominance of maritime influences in their climates, most high-latitude islands were subject to alternating glaciation and deglaciation during this period. Even high subtropical islands like Hawai‘i experienced such climate changes and associated processes which have left their mark on the island’s modern environment (Sheldon 2006). In general, the temperatures of lower-latitude islands did not change much during the Quaternary although many experienced aridity, the legacy of which is visible today. The grasslands that exist in many parts of the Pacific Islands were once thought to be wholly anthropogenic – created only after humans arrived and began burning the native forests – although now many such grasslands are suspected to be far older, a relic ecosystem that developed during the arid Last Glacial Maximum about 18,000 years ago (Nunn 1994).

Quaternary temperature fluctuations also drove sea-level changes that fundamentally altered the geography of the ocean basins and their islands. During periods of low sea level (the ‘ice ages’), island areas increased and islands became closer together, facilitating biotic dispersal. Island climates changed because of the increased altitude. Conversely, during periods of comparatively high sea level (interglacials), islands were smaller, farther apart, and many islands which were ‘high’ 18,000 years ago during the Last Glacial Maximum may today only poke a few metres above the ocean surface.

(c) Extreme or rapid events

Viewed in the context of long-term environmental evolution, extreme or rapid events may in fact have lasted decades rather than days but still have left a profound and long-lasting legacy.

A good example of a climatic event that was both extreme and rapid compared to times before and after is the Younger Dryas, an approximately 1,000-year long reversion to almost full glacial climate that began around 11,000 years ago during the period of postglacial warming. Tropical islands were among those affected by rapid temperature fall during the Younger Dryas; sea-surface temperatures 10,200 years ago in the Vanuatu archipelago were around 5°C cooler than today (Beck et al. 1992). Changes in the rates of upwelling around Caribbean islands during the Younger Dryas (Overpeck et al. 1989) would have had significant impacts on their biotas.

A similar, more recent example is the ‘AD 1300 Event’, a period of rapid cooling and sea-level fall that affected the Pacific Islands (and perhaps elsewhere) for around 100 years beginning about AD 1250. Among the direct environmental effects were the emergence of islands made of surficial materials, the emergence of nearshore coral reefs, and degradation of lagoonal ecosystems that forced a food crisis for coastal-dwelling humans that led to centuries of conflict (Nunn 2007).

More rapid, catastrophic events have also figured in the long-term evolution of island environments, although the identification of such events is often controversial. Giant waves, from storms or tsunami, have sometimes left behind diagnostic deposits; an example comes from the Okupe Lagoon in New Zealand (Goff et al. 2000). Collapse of island flanks, even entire islands, is an important process in their long-term evolution; such events have been isolated by geological survey, as in the case of Johnston Atoll in the Central Pacific (Keating 1987), and by myth, as with the now-vanished islands of Tuanahé (Southern Cook Islands) and Vanua Mamata (Vanuatu) (Nunn 2009).

(d) Pre-modern human impacts

Owing to the vulnerability of most island ecosystems, the effects of human colonisation are often regarded as having been immediate and massive. While there are many case studies suggesting
that this is the case – such as the charcoal ‘spikes’ in swamp sediments on several western Pacific islands (Hope et al. 1999) – there is evidence to suggest that the connection is more ambiguous (Nunn 2001). Much vegetation change that led to landscape change was brought about by human commensals, such as rats, or accidentally-introduced exotic plants. The origin of the singular gullies (named *lavaka*) on Madagascar was debated for a long time, with human impact as a leading explanation; it is now clear that *lavaka* have climatic origins although they may have been enlarged by human activities (Wells and Andriamihaja 1993).

Several authorities have pointed to Easter Island and the 14th-century collapse of its society as an example of its inhabitants committing ‘ecocide’ by cutting down all the island’s trees to support statue construction (Bahn and Flenley 1992, Diamond 2005). Such explanations, while salutary and more readily apprehended on smaller islands than on continents, are still contentious and alternatives have been mooted (Stenseth and Voje 2009). Principal among these is the climatic explanation which sees sea-level fall (and water-table fall) during the AD 1300 Event, reducing the amounts of food available to island peoples. This in turn forced lifestyle changes, sometimes what might be described as societal ‘collapse’, marked by conflict in many places (Nunn 2007).

The AD 1300 Event led to people throughout the Pacific abandoning their coastal settlements and establishing new ones inland, commonly in fortifiable locations such as hilltops and caves. This led to an abrupt impact on the inland parts of many islands, resulting in their degradation and often an associated response in downstream and coastal areas (Kumar et al. 2006). Deliberate adaptations for the enhancement of agricultural production also remain visible on many islands today. This is true especially of agricultural terracing, introduced to many tropical Pacific Islands during the arid Little Climatic Optimum, warm period (AD 750–1250) that preceded the AD 1300 Event and the ensuing Little Ice Age (AD 1350–1800) (Nunn 2007).

The beginning of plantation agriculture on many islands, often coincident with the start of colonial history, resulted in major changes to their environments. Illustrative of this are the rates of erosion from various environments in the Philippines: areas under primary forest (largely undisturbed) lose around 3 tons/hectare/year; while areas of open grassland (converted from forest) lose 84 tons/hectare/year; and overgrazed areas lose 250 tons/hectare/year (Coxhead 2000).

**Influences on contemporary island environments**

Many island environments today bear little resemblance to their historical counterparts. Wholly urbanised islands like Manhattan (New York), Malé (Maldives) and Stockholm (Sweden) and some in Hong Kong are extreme examples of this situation. For most others, it makes sense to separate human influences from natural (non-human) ones. Among the latter, climate change and sea-level rise, as well as catastrophic events, are selected for discussion.

**(a) Climate change and sea-level rise**

Within the past hundred years, most islands have experienced surface temperature warming and sea-level rise. This has caused a range of problems although it is sometimes difficult to separate non-human from human causes. For example, vegetation change during the 20th century on islands is more likely a consequence of direct human impact although some may have been due to warming and, particularly in low-lying coastal areas, to groundwater salinisation resulting from sea-level rise.
Warming has also affected ocean-surface temperatures, and this increase is implicated in recent changes to a number of shallow-water marine ecosystems, notably coral reefs. When ocean-surface temperatures exceed 30°C for prolonged periods, as they have done increasingly over the past few decades, corals will sometimes be stressed to the point that they eject their symbiotic algae, thereby losing their colour (bleaching) and dying. Such ‘coral bleaching’ is likely to affect island reefs more frequently in future decades if ocean-surface temperatures continue rising, and many coral reefs are likely to become barren and nearby beaches starved of calcareous sediment (Hoegh-Guldberg 2011).

It is also likely that warming over the past few decades has contributed to both the changes in the frequency and intensity of tropical cyclones (hurricanes or typhoons) as these usually develop only in ocean areas where the surface temperature exceeds 27°C. In the tropical Pacific, recent warming has increased the area within this condition is met resulting in more frequent tropical cyclones over the past 50 years that occurred increasingly ‘out of season’ and affect islands farther east than what was long regarded as the cyclone-prone region. Tropical Cyclone Ofa, which slammed into the islands of Samoa in 1990, was the first such storm to affect them for more than 35 years. Since 2007, in line with global climate models, tropical cyclone frequency in the Pacific has declined, although the intensity of such storms has increased. Tropical Cyclone Winston, that affected Fiji in February 2016, had the strongest winds ever recorded in the southern hemisphere (Anonymous 2016).

The problem with sea-level rise being portrayed as ‘the’ issue with which islands will have to cope in the 21st century is that it encourages poorly-informed and cash-strapped island governments to overlook more pressing problems, both those associated with climate change (such as changes in precipitation regime) and those not linked to climate change (such as population growth) (Nunn 2004, Baldacchino and Kelman 2014). That said, sea-level rise represents an important challenge for many island communities, particularly those which are ill-equipped to meet it. In many poorer island countries, communities which are only marginally within the cash economy often raise huge sums to build seawalls, believing these will protect against coastal erosion, both today and in the future. Most such seawalls collapse within a few years of and are often subsequently abandoned (see Figure 3.6a); a cheaper and more sustainable solution is to plant (often re-plant) the mangrove forest that once fringed these islands’ coasts (see Figure 3.6b). As part of a multi-goal coastal rehabilitation programme on Marinduque Island in the Philippines, mangroves are being allowed to grow out over potentially toxic copper tailings in Calancan Bay.

(b) Catastrophic events

Owing to their youth and location, many islands are especially vulnerable to catastrophic events, and many island environments (and peoples) reflect their influence. Many islanders live in the shadow of active volcanoes, sometimes because there is nowhere else to go but often because of the fertile soils and dependable water supply characteristic of many such locations. Examples include the people occupying Tofua Island (Tonga) and those whose food gardens are scattered across the slopes of Merapi Volcano (Java). In the modern age, volcanic catastrophes affecting islands are mostly containable in that they can be predicted and appropriate action taken to avoid unnecessary impacts and loss of life.

Yet, some of the world’s largest eruptions have occurred on islands and produced effects that were often felt around the world. The 1883 eruption of Krakatau Island (Indonesia) (see Figure 3.7) produced devastating tsunami and eventually destroyed the island (Simkin and Fiske
The earliest response was to build a seawall, using largely rock from the fringing coral reef. The seawall was undermined by wave erosion, collapsed and was rebuilt repeatedly until it became clear that this was not an effective long-term option. This view shows part of the degraded seawall, and the land behind, into which storm waves penetrate and erode the coastal flat on which the village lies.

The villagers are now replanting a mangrove forest along the worst affected part of the shoreline. This option is sustainable, effective and will enhance the nearshore ecology. The only difficulty is that it may take 25 years for the mangrove fringe to reach maturity. Mangroves are grown in a nursery and then planted out at regular intervals when they are about 80 cm tall.
Figure 3.7 The eruption of the Indonesian island volcano of Krakatau (Krakatoa) in August 1883 was one of the largest in recent time. Shock waves circled the planet seven times; the eruption was heard in Perth (Australia), more than 3,000 km away; and in this part of Indonesia the dawn did not appear for three days because of all the ash in the air. More than 36,000 people perished, many drowned by the huge tsunami waves generated by the collapse of the islands into an undersea caldera.

Source: This figure was published in 1888 as Plate 1 in the Royal Society’s report of the Krakatoa eruption. Wikimedia Commons, https://en.wikipedia.org/wiki/1883_eruption_of_Krakatoa.

Yet it was considerably smaller than the AD 1452 eruption of Kuwae in Vanuatu – one of the largest in the past 10,000 years – that also destroyed the island, producing a 72-km³ submarine caldera (Eissen et al. 1994) and ejecting so much ash into the atmosphere that northern-hemisphere weather was drastically affected for several years (Pang 1993). The largest eruption of the past two million years occurred at Toba (Sumatra) and formed a 3,000-km² caldera; pyroclastic flows covered an area of 20,000 km², and ash covered an area of about 4 million km².
Large earthquakes may also have catastrophic effects on islands, sometimes causing them to rise, sink or tilt. Many islands close to convergent plate boundaries rise co-seismically (when earthquakes are coincident with uplift). Parts of the coast of the island of Taiwan are stepped, indicating the effects of repeated co-seismic-uplift events (Huang et al. 1997) and terracing the landscape in ways that facilitate plantation agriculture. During the 1964 Prince William Sound Earthquake in the northeast Pacific, parts of Montague Island rose 11.3 m in a few seconds while parts of Kodiak Island sunk abruptly by more than 2 m (Plafker 1972). Co-seismic subsidence was also the cause of the destruction of Port Royal in Jamaica in 1692 (Gragg 2000).

The history of Pukapuka Atoll (Cook Islands), passed down orally through generations, is dominated by one event named in the vernacular te mate wolo (the Great Death) that marks the time when a huge wave swept across the atoll, carrying away most of its inhabitants (Beagle-hole and Beaglehole 1938). Such waves can obliterate entire islands, and can strip them to their unweathered sedimentary foundations. Yet, paradoxically it might seem, they can also create and enlarge such islands by driving reef detritus onshore. Much of the variation is attributable to the morphology of the ocean floor over which the wave approaches the island, and the amount of sediment it is carrying when it reaches the island coast.

Island environmental futures

Many of those responsible for managing island environments are grappling with multiple environmental-related problems, almost all accentuated by islandness, with insufficient financial or human resources at their disposal (Nunn 2004). Most professionals who are managing island environments have also been trained in continental environments and assume—often with disastrous consequences—that islands are merely continents in miniature (Doumenge 1987). There is no shortage of bleak prognostications for the future of island environments: from the possibility of climate change causing the Gulf Stream to weaken bringing cold wet summers to the Western Isles of Scotland; the flooding of Caribbean island wetlands with huge ecological consequences (Nicholls et al. 1999); to the likelihood that entire nations of low-lying islands like Tokelau and Tuvalu could disappear (Lewis 1990).

A way forward is to recognise island environments—perhaps with isolated and archipelagic subsets—as distinct and requiring effective solutions to environmental problems devised and implemented by persons with the long-term interests of islands at heart. Many islands are regarded as economically ‘under-developed’: this explains why sustainable environmental development is invariably considered as secondary—despite many fine speeches—to income-generating activities by those island leaders.

Typically as a result of unsustainable demands being made on them, the environments of most inhabited islands have deteriorated over the past few decades, something that is likely to continue on many as population densities increase and climate change has an increasingly significant effect on livelihoods (Nunn 2013). While this is likely to one day lead to radical responses from island leaders, particularly around resource conservation and stewardship, it will inevitably also lead to island abandonment. Nowhere is this more apparent than on inhabited atoll islands (such as those in the island nations of Kiribati, Marshall Islands, Maldives and Tuvalu) where rising sea level is often causing both freshwater lenses and habitable land to decrease in size (Connell 2016).
References


