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Collapse and recovery in a remote small island—A tale of adaptive cycles or downward spirals?

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ABSTRACT

Few studies consider how social-ecological systems recover from disturbance. We consider the small semi-autonomous island of Rodrigues (Indian Ocean). Based on semi-structured interviews ($n = 70$), a fisher survey ($n = 73$), weather data and official records we build a timeline of key events. We tabulate local perceptions (5+ mentions) of changes (social, economic and natural capital) and look for signs of adaptive cycles in the island's social-ecological past. Rising human pressure and extreme weather event impacts are reported since first settlement. We propose a recent "collapse" phase catalysed in the 1970s by severe drought, based on respondents' perceptions of still-ongoing changes in farming and fishing, water, external dependence, migration and inter-island political change. Connectivity (flows of people, goods, information, money, power) appear to have strengthed local island recovery, but degradation continued, not least due to water scarcity and a lack of shared political vision as Rodrigues became more tied into the wider world.

Overall, our findings suggest social-ecological systems may get stuck in a post-collapse recovery without any new structure emerging, presuming adaptive cycles can even be detected. Data gaps and global change redefining spatial and temporal scales could mean the adaptive cycle's usefulness is limited in development policy-making contexts.

1. Introduction

Issues of how people respond to change catalysed by external stress, and how society reorganizes afterwards, may determine if societies survive or collapse (Gunderson and Holling, 2002; Diamond, 2005). Coastal ecosystems with rising populations are highly subject to feedback effects between social and ecological elements as they face increasingly intense environmental change (Turner, 2000; Adger et al., 2005b). Small islands are often most exposed to such risks and impacts (Pelling and Uitto, 2001; Tompkins and Adger, 2004; Meheux et al., 2006; Cherian, 2007). Small and marginal "sister" islands within island states may be particularly at risk as they are often seen as a burden (van Beukering et al., 2007) and receive fewer financial resources. For example, coral reefs at the core of small island social–ecological systems are globally threatened and face collapse, with consequent loss of livelihoods (Scheffer et al., 2003; Carpenter, 2008). This can be linked to multiple stressors including human activity and external factors such as climate change and risks of ocean acidification (Hughes et al., 2003). Island vulnerability needs to be better understood (Pelling and Uitto, 2001; Gowrie, 2003; SOPAC, 2003) for how it relates to sustainable development (McMichael and Butler, 2003; Kerr, 2005; Adger, 2006; Young et al., 2006a,b). Studies of natural hazard impacts in small islands often focus on the short-term rather than long-term, and economic more than social and ecological aspects (Meheux et al., 2006).

2. Resilience

Resilience concepts focusing on dynamic change and adaptation – or potential for recovery from damage – are proposed as a replacement for sustainable development paradigms focused on "lifestyle and production" (e.g. in Holling and Gunderson, 2002; Abel et al., 2006). As a property of social–ecological systems resilience may be seen as the amount of change a system can take while keeping the same function/structure; the extent of a system's ability to self-organise; and an ability to build and increase the capacity for learning and adaptation (Walker et al., 2002; Folke, 2006; Brand and Jax, 2007). Policy may aim to prevent a system from moving to an undesired configuration in the face of external stress or disturbance whilst nurturing elements that

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enable the system to renew and reorganise. Recent reviews highlight the policy relevance to adaptively managing vulnerable social–ecological systems of understanding two critical stages of Holling's Adaptive Cycle – collapse and reorganisation – to forestall and overcome crises (Abel et al., 2006).

2.1. Aims and objectives

Few field studies focus on collapse and reorganisation (Folke, 2006), and we are unaware of any for small islands. We aim to identify historical and recent social and ecological change in a sub-national small island where development is focused a common pattern of fishing, farming and tourism. We look for factors which may have influenced collapse and recovery from disturbances such as natural hazards. We discuss the relevance of Holling's conceptual Adaptive Cycle in line with our findings.

2.2. Research site

Small island studies relate mostly to state rather than non-state islands and regions, although climate change risks to both are recognised (Brown et al., 2001; Abel, 2003; Kerr, 2005; Tompkins, 2005). Remote Rodrigues island (18.3 km long by 6.5 km wide) lies at 19′4″S, 63′25″E in the inter-tropical zone of the south-western Indian Ocean (Fig. 1) 600 km east of its central government in the main island of the Republic of Mauritius (henceforth MIOM) (McDougall and Upton, 1965). Rodrigues (104 km^2) steep volcanic flanks and deep narrow valleys rise to 398 m (McDougall and Upton, 1965). The island has one of the Indian Ocean's largest reef lagoons (approximately 200 m^2). With exceptions (Gade, 1985), Rodrigues is barely researched beyond natural sciences. Semi-autonomy (2001) raises its relevance to how islands respond to disturbance (Bhikajee, 2001; Rees et al., 2005; Payet and Agricole, 2006).

3. Methodology

3.1. Conceptual framework

Specific methodologies for research on social–ecological systems (Folke, 2006) remain in explorative stages (Walker et al., 2002), including for reefs (Anon., 2007). The Adaptive Cycle is a recognised concept for analysing social–ecological systems, for example in Africa (Abel et al., 2006). In Australia, Walker et al. (2002) use the Adaptive Cycle (Fig. 2) to analyse historical events and show how external disturbance can change the capacity of a social–ecological system to support livelihoods—e.g. a rural water catchment district hit by drought.

In marine contexts common to islands such a natural system may pass into an irreversible ecological state, for example through over-fishing (and/or climate change) leading to loss of live coral cover in a reef (Hughes et al., 2005). Such a shift in natural "state", representing loss of ecological resilience to disturbance, may then translate into a long-term collapse—of a fishery, livelihoods and capacity to cope with future disturbance in the social system. Seixas and Berkes (2003) use the Adaptive Cycle in a South American lagoon context relevant to tropical fisheries. Target species' population lifecycles and fluctuations were linked to the natural opening and closing of a gap through a sand bar separating brackish and sea water. Policy (e.g. enforcement or gear) impacts are analysed over decades. Other authors describe windows of opportunity for policy to nudge systems into recovery (Cocks, 2003). The Adaptive Cycle has more recently been used to plot future scenarios (Evans, 2008).

3.2. Research methods

We take Rodrigues Island as our sub-national scale of study due to its small size within wider Mauritius (henceforth). MIOM is considered to be the next social–ecological scale up due to national social, economic and political links and bio-geographical connection.

Mixed methods are recommended for social research in Africa (Bulmer and Warwick, 1993; Bunce et al., 2000). We develop timelines used by Walker et al. (2002) to identify possible phases of the adaptive cycle. To do this we referred firstly to the limited secondary data and literature on Rodrigues history, e.g. colonial administrative records (North-Coombes, 1971), government reports (CSO, 2000, 2005), development plans (e.g. KPMG, 2006; UNDP, 2006) and the limited scientific journal literature (Oliver and Holmes, 2004). To cover recent years and overcome a paucity of secondary data, we completed 70 semi-structured interviews (SSI) with Rodriguan island elders, officials, resource users and others with direct or indirect influence over policy formation (Seixas and

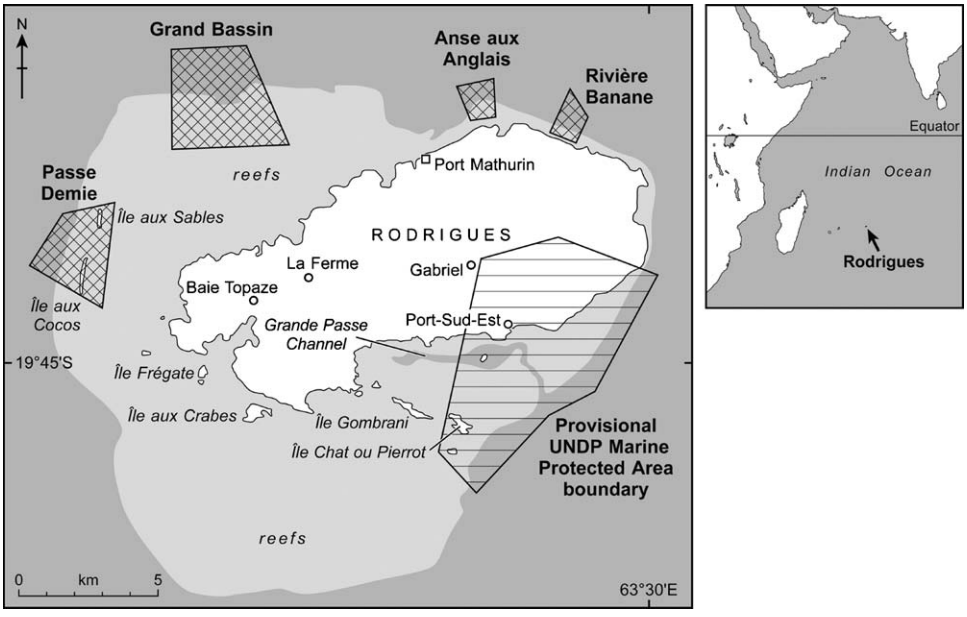

Fig. 1. Map of Rodrigues, showing actual and proposed locations (boxes) of new marine reserves and a Marine and Coastal Protected Area. (Lagoon reef flat in light grey.)

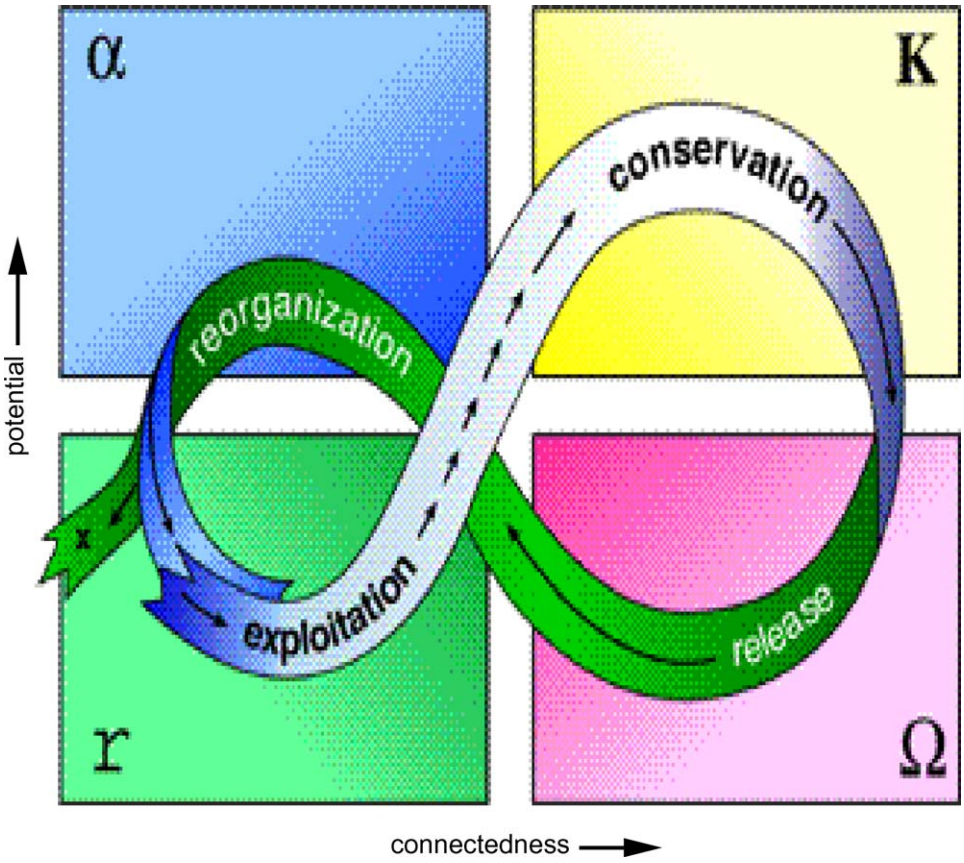

Fig. 2. The adaptive cycle and its proposed sequential phases (Holling and Gunderson, 2002), showing relationship between accumulation (r) and conservation of capital (K) – as defined in Box 1 – and its release or "collapse" (Ω) and re-organisation (α) or "recovery". Potential for resilience is reduced by exploitation (or accumulation) of capital leading to its collapse phase Ω). Resilience may be rebuilt through conservation and reorganisation. Components of resilience may have cycles at slower/faster rates, at different scales. There may be interconnected multiples of Adaptive Cycles across space and time. Connectedness on a social level may refer to, for example, integration of credit and trading systems, and, on a natural level the patchiness of coral reefs. As an attribute of resilience it may decrease with exploitation (r), be restored through conservation and degenerate if this fails. Social and ecological resilience may not even be linked (Adger, 2000).

Berkes, 2003; Abel et al., 2006)—including government, finance, donor, NGO, academic, fishing, farming, livestock and tourism sectors. Rodrigues' small size meant relevant interviewees were easily identifiable through snow-balling techniques (Bunce et al., 2000). Interviewees described their memories of Rodrigues, how it had changed over time, why, and what could help the island's future. Key dates were used to focus interviewees on the timing of events. Interviews were recorded for translation from French and/or Creole into English. Dated outputs were added to the historical timeline (Walker et al., 2002). Quotations were extracted from manually coded texts into key themes representative of general opinion held by respondents met in 12 months of research in Rodrigues ending November 2006. We used accumulation and release of "capital" as a shorthand for describing social–ecological changes in resilience terms (Box 1). We looked for trends relating to changing capitals (Box 1) as raised spontaneously initially by three respondents, and confirmed in later SSI by at least two other respondents, whether or not prompted. Our SSI were exploratory and iterative to overcome a lack of prior research. Degradation is already reported in MIOM and Rodrigues but how elements of this may be interconnected are little discussed (Gade, 1985; Ramessur, 2002). We arrived with no a priori expectations beyond the social and economic development constraints common to islands in general, and in particular twin islands facing increasing resource scarcity and climate change (Briguglio, 1995; Baldacchino, 2002; Lal et al., 2002; Tompkins and Adger, 2002; Tompkins, 2005; Campling, 2006; Cherian, 2007; van Beukering et al., 2007). Outputs from our case study were not intended for statistical comparison between different interview groups (Gelcich et al., 2005) and we developed a general, island storyline (Hajer, 1995). We used outputs to define a stratified random survey of 93 fishermen (Bunce et al., 2008) with elements to complement this qualitative survey on perceptions of disturbance affecting livelihoods. We processed corresponding weather data into a five-year moving average to identify anomalies and compare with interview outputs.

4. Historical context

Rodrigues was charted (1528) and initially settled (1602) by Europeans, mainly French, with a contingent of slaves from

Box 1. Capital in social–ecological systems (adapted from Abel et al., 2006).

Social: social networks, formal and informal rules mediating interactions between humans, humans–environment. Includes cultural, institutional, bonding (between similar individuals) and bridging capital (between unlike groups)	**Human**: Individual knowledge/skills/ competences of that promote creation of personal/social/economic well-being
	Natural: The ecosystems that support humans
	Physical: Technology and infrastructure
	Financial access to money

Mozambique, Madagascar and wider Africa (Gade, 1985). Environmental degradation on land was recorded early on (Oliver and Lynch, 2004), with tortoise then turtle depletion and extinctions (Dodo-like bird Solitaire: mid-1700s). Governance of Rodrigues was haphazard and swayed from afar by ideas and events in Europe, such as reports of discoveries of Eden in the Indian Ocean (Grove, 1990, 1995), religious and Napoleonic wars in Europe causing emigration, and naval battles extending to the Indian Ocean amid globalising trade patterns (Cape route to East India). The population rose after British slavery abolition laws (1807–1830), with freemen using little-regulated African swidden-farming practices (Gade, 1985). The island, absent democratic rule, was subject to sometimes strictly autocratic officials (1830) on rapid rotation from the colonial seat in MIOM (North-Coombes, 1971; Gade, 1985), but Rodriguan elite families at times forcefully opposed them (North-Coombes, 1971). Conservation and land rules were routinely flouted and tax receipts were low.

The British still saw Rodrigues (early 1800s) as a potentially "useful appendage" to MIOM in food supply terms, but Rodrigues suffered economically from poor trade terms, both internally and externally for produce, livestock and salted-fish exports. Mistrust, lawlessness and exploitation characterised fishing on both islands. By 1867 (pop. 1100) officials doubted Rodrigues' usefulness (North-Coombes, 1971). Indian labour was brought to sugar farms in MIOM but not Rodrigues, as it was unsuitable for plantations, and MIOM ethnically diverged from Creole Rodrigues. The first visit by a governor of MIOM did not happen until 1880, when a rice debt-for-labour swap was agreed to counter falling tax receipts after a harsh drought, typhoid and near famine.

Rodrigues' regular devastation by cyclones, droughts and crop pests led to rising dependence on MIOM. Repeated official calls in the late 1800s to limit degradation (e.g. tree felling on slopes, soil erosion) were ignored (North-Coombes, 1971). Such hardship and neglect of Rodrigues continued. The island lost residual strategic trade value after cutting of the Suez Canal (1886) trade route to India. Declining food security in MIOM due to sugar farming meant it still needed Rodriguan food exports. As steam replaced sail ships traders arrived to boost Rodriguan fish and octopus exports. Accelerated degradation of marine resources (beyond turtles) may date from this turn-of-the-century era. Natural hazards (drought/cyclone) intervened, forcing men from farming into fishing, again raising official concern over the fishery. New rules for fisheries (1904), forestry, water, labour, quarantine, trade and stray animals had little respect or impact. The few coastal fisheries reserves by 1906 had failed partly due to poor delineation, corruption and enforcement (North-Coombes, 1971; CSO, 2005).

Island degradation continued despite less population growth (1890–1915) (CSO, 2005). Agricultural and other experts' calls for reforms were ignored as colonial powers focused on World War I. Open access natural resource use (1936/1937) still prevailed on land and sea (Gade, 1985; Paillat, 1999) during inter-war droughts and cyclones. Native plants declined after 1938 (Strahm, 1989), and invasive species spread (Kueffer and Vos, 2004). Canker attacked trees. Officials warned of Rodrigues as an "island of limitations" and "a burden to be supported" (1934)-urging emigration (Brookfield, 1957) to avoid the community's "ultimate destruction" (North-Coombes, 1971). Seine rules were set (1939) but official efforts to end degradation flailed as the Second World War approached (Gontran, 2006). Environmental pressure eased with enlistment (Brookfield, 1957), but the post-war population doubled to 24,000 (1945–1972). A seine monopoly ended as post-war population food needs grew and available land fell with development (Gontran, 2006).

Rodrigues' run-up to Mauritian independence was marred by harsh cyclones, with records around 1968. Donors (FAO) from the 1960s on concluded that much of the island should not have been cultivated. Overpopulation fears (Brookfield, 1957) meant emigration became a national priority (pop. 1962 = 18,500) (Brookfield, 1957). As crop yields fell, the colonial era ended with violent post-cyclone food riots (Gontran, 2006). Air and ferry transport improved links with MIOM, but relations between the two islands was tense. Rodriguans refused to raise the Mauritian national flag for a year (1968) as some feared Hindu dominance within the newly independent Mauritius (Gontran, 2006).

5. Results

Referring to our timeline (Fig. 1), earlier settlements and livelihoods (social system) appear to have waxed and waned as a function of tortoise/turtle availability (ecological system) for ship victuals. Beyond this, links between social and ecological systems are less clear. Regular natural hazards certainly checked island development, for example severe cycles in 1863–1864, 1872–1873, 1875–1876 and 1962–1963, with the 1875 cycle particularly devastating (North-Coombes, 1971) (Table 1).

A long-term pattern of degradation appears to have developed, but despite this, and species reductions and extinctions the human population expanded exponentially. Rodriguans appeared to cope though an adaptable mix of fishing, farming and trading livelihoods, which still allowed for limited exports of fishing and farming surplus. We suggest there were at least risks of social and/or ecological collapse on several occasions—for example around 1830, 1870, 1900, 1920 and 1970. Sporadic official alarm suggested scope for action over resource use patterns, for example in 1794, 1839, 1860s, 1880s, 1901, 1919, 1945, and 1970s. Such "windows of opportunity" may have been missed in the absence of a conservation ethic in Rodrigues, or its colonial and then national administrations. Overall, we lacked sufficient and reliable secondary data for clearly identifying land–sea ecosystem state changes relating to livelihoods in a way clearly indicative of social–ecological collapse or recovery.

5.1. 1970s collapse?

We turned to more detailed data and our interview outputs covering recent decades to explore the possibility of collapse and recovery occurring within living memory. Interviewees' descriptions of Rodrigues related to events affecting their livelihoods since the 1950s. Referring back to earlier definitions of capital (Box 1) interviewees' accounts suggested that by the 1970s Rodrigues was already weak in social and ecological terms ahead of a severe five-year drought during the 1970s El Niño Southern Oscillation event (ENSO) (Trenberth, 1997):

Natural capital: A long-term loss of land–sea biodiversity; deforestation extending to cyclone resistant species limiting chronic soil erosion and promoting cloud-seeding; degradation of the lagoon fishery supporting local livelihoods.
Social capital: A lack of effective governance, taboo or indigenous belief system relating to the environment. Political mistrust, some rooted in ethnicity at inter-island level, between Rodrigues and MIOM as they became closer after independence.
Human capital: Migration of educated and skilled sections of society. Marginalisation of Creoles culminating in ethnic tension/riots in MIOM in the 1960s (and later in 1999).
Physical capital: Poor public service, infrastructure and outside links/communications.
Financial capital: Little capital, credit and land rights for diversifying livelihood away from a subsistence economy based on rain-fed farming.
Technological capital: Minimal investment. Bench-terracing (World Food Programme) created work (financial capital) and

Table 1
Timeline showing problematic identification of phases of collapse/recovery in social–ecological systems in the Adaptive Cycle (Gunderson and Holling, 2002). Periods of degradation and potential for recovery are evident but evidence of Adaptive Cycles in Rodrigues' social–ecological system were hard to identify due largely to long-term data gaps. We rely on our recent data to propose a conceivable collapse starting in the 1970s (shaded).

Years	Events relating to degradation/collapse or scope for policy intervention
1528	Rodrigues charted, uninhabited. Tree and tortoise abundance
1602	Periodic European (French) settlement
1761-67	Tortoise in steep decline and last sighting of (extinct) Dodo-like Solitaire
1791	Permanent settlement after French revolution. Slaves. Last tortoises. Turtle/fish exports.
1794	Tree-felling rules (slopes), cultivation, livestock, boat-building, autocracy
1800	Pop. cut to deter British (E. Indian trade growth). Few trees (1803). Permanent fishing camps
1809	British end French rule. Wood/streams OK. Island seen as useful gain
1812	Fish decline first noted. Oyster depletion
1839	Slavery ban. Crown land rules
1830-39	African swidden farming. Lawlessness. More fishing camps expansion. Pop. growth (<400)
1840-50	Cyclone (1844). Rodrigues state "lamentable". Forest fires, land erosion. Poverty, poor trade terms
1860	Cyclones wreck crops/livestock. Forest fire, pests, disease, poverty/debt
1860	Land reform (rent). Public institutions inc. court, clergy, school, tax. Popn accelerating (1000)
1870-80	Severe 3-yr drought, then cyclones. Agriculture export potential downgraded. Warnings over tree-felling.
1876	Century's worst cyclone. Drought, near famine, rice imports/hoarding. Fishermen debts. Typhoid – excrement dumping in lagoon. Tax receipts down
1880-84	First visit by Mauritius governor in 70 yrs. Rice debt swap. Fish, forestry etc rules. Model farm. (Pop. 2000)
1884-1900	Political exclusion (Mauritius legislature). Rice imports. Tobacco exports end. Shipping disrupted (trade change Cape to Suez, sail/steam). Poor state: farms, fish, livestock, water, trees.
1901/06	Cable station–economic boost. Food security in Mauritius down (sugar expands, popn grows)
1901-14	Large fish decline. Fishery rules flouted (season/gear/area). Fishery development uneconomic. Experts warn of wide forest/soil/fishery and general degradation. Many reforms urged - ignored. War-time deterioration. Temporary officials. Land cleared for building, tree felling in watercourses
1919	Seine net fishing ban. Reserves redefined. Fisher total stabilises. Enforcement poor. Pop 6000
1920-37	Rodrigues officially "island of limitations", "future "burden" after droughts, cyclones, (goat) erosion, pest, low. Official fears of "island's ultimate destruction" ('33). Canker kills trees. Pop rise eases
1938-45	War, corrugated iron, relief work projects ease human pressure but plant decline noted
1945-50	Popn rise – emigration urged. Severe cyclones (47), erosion. Turtles absent. Pop 12,000
1955	Island terracing, agric expansion, schools expand. Stronger housing (concrete)
1959	Severe run of record cyclones: 8 up to 1968. Pop. rising fast to 18000
1968	Independence (from UK). Seine ban. Air links, port. Rodrigues politicised. Pop. 24,000
1974-78:	Severe drought. Hardship, erosion, cyclones. Farm collapse. Rise of island leader. Emigration
1980-85	EU erosion project/development. Fishing subsidy. Fibreglass boats. Autonomy bid. Pop. stabilised
1995-98	Falling fish catch. Coral bleaching. Ethnic tensions in Mauritius. Divisive politics. Water riot
2000-07:	Regional Autonomy ('02), fishing incentive cut & conservation wins support. 1st local election power shift. >90% budget dependence on central government of Mauritius. Tourism sluggish. Pop 40,000

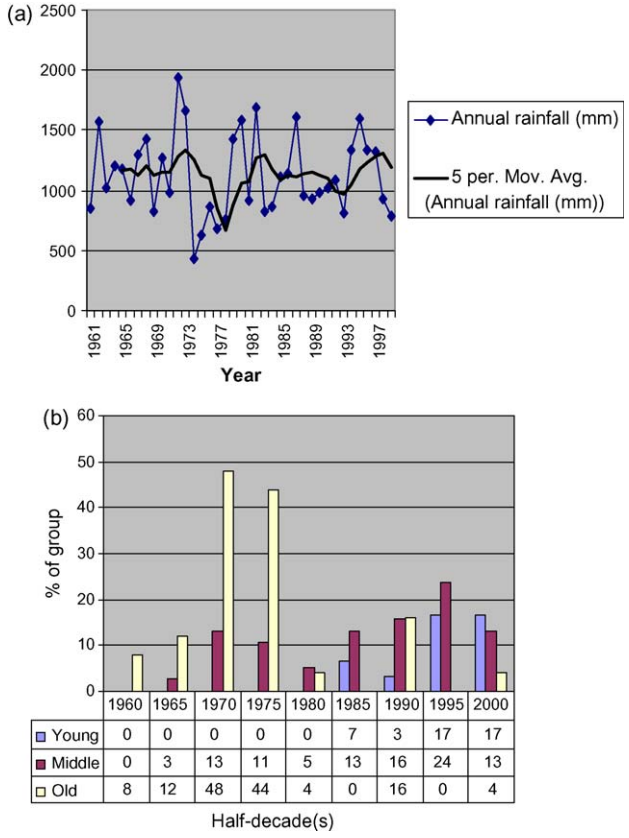

Fig. 3. (a) Rodrigues' annual rainfall 1961–1997 (Pte Canon) as a 5 year moving average showing the severity of a 1970s drought with hard cyclones at each end (*Data*: *Mauritius Meteorological Office*) and (b) three generations of fishers' ($n = 93$): of which young = 18–29 years $N = 30$, middle-aged = 30–49 years $N = 38$ and old = 50–80 years $N = 25$) were questioned about period(s) of ecological change: "Has there been a time which radically changed Rodriguan ability to fish and farm in balance with nature?" and "If so, when?". Year of cited change (x-axis) and percentage of age group citing year (grouped into half decades) show on y-axis. Boxes below x-axis show breakdown of number of respondents by age group (%).

> limited erosion (retained natural capital) but crop yields were falling due to severe cyclone impacts and farming practices.

The severity of following 1970s drought, bracketed by harsh cyclones, is clear from local weather data (Fig. 3a). Fishers old enough remember the period as the harshest, including in terms of livelihood impacts (Fig. 3b and Table 2).

The 1970s drought and its impacts are reported by Rodriguans in catastrophic terms. One official referred to an Easter Island scenario, but more usually the island's plight is described as an ongoing "vicious cycle" of deforestation, overgrazing, soil erosion and drought. Respondents indicated that this accelerated during and after the 1970s:

Based on our interviews we considered that a collapse (Ω) phase may have begun in the 1970s, catalysed by a severe drought. Interviewees' perceptions broadly indicated losses of capital suggestive of loss of resilience (Abel et al., 2006) (Table 3):

In Table 4 we tentatively suggest how changes raised by interviewees and secondary data are linked through the adaptive cycle, focusing on what we consider here to be an unclear delineation between collapse and recovery.

Given the lack of extensive historical and weather data on Rodrigues it is unclear if droughts in preceding centuries were as severe in terms of impacts. However, one century ago (pop. 1500) officials did speak of Rodrigues' droughts in terms similar to perceptions of the 1970s drought—despite an intervening 20-fold population rise:

> "There had been a succession of droughts and cyclones which had destroyed all crops and turned into fishermen large numbers of inhabitants who (normally) were purely farmers. Larger fish were driven away from waters where in 1890 one could catch by line in a day as much fish that could now be caught now in two months" (Rouillard, 1904, quoted in North-Coombes, 1971).

Older interviewees often referred to population growth surrounding the drought as a problem for Rodrigues. Exponential growth rates preceding known periods of social–ecological stress – in the late 1800s and 1970s – remain the two highest recorded for Rodrigues (CSO, 2005). The 1970s saw a rise from 24,000 to around 33,000 over 10 years—equivalent to the rise in the first 340 years of settlement (CSO, 2005). The growth rate collapsed after the 1970s (Fig. 4) as Rodriguans migrated mainly to MIOM.

Water shortages emerging as a critical issue related to the 1970s drought deepened in severity thereafter. Droughts appeared to be feared more than cyclones:

> "After a cyclone we could still have a winter harvest – plant some vegetables and some onions, try to shelter the animals and give them grass. But with (1970s) drought – nothing. We planted

Table 2
Rodriguans' comments suggesting a severe 1970s drought acted as catalyser of rapid social–ecological change—or conceivably a "collapse", per Holling's adaptive cycle.

Island trader	"Nature has changed—that started in the great drought of 1974"
Enforcement	"In 1974 we had a huge drought due to deforestation—even eucalyptus didn't grow"
Ministerial level	"When I talk about Rodrigues I talk about a 'Before' and an 'After'. The before is before the 1970s, when Rodrigues produced a lot more (fishing and farming). When the land was much farmed, not so many people working for the government … did not have to struggle to make a living …"
Livestock official	"Before the drought … There were cyclones, there were many natural trees … Rodrigues was in a more natural condition … fewer people … the rivers flowed all year … endemic trees …"
Regional leader	"The more they killed the forest the more the exodus to the sea (to fish) was accentuated. Crops were rotten and the cows died. There used to be fishers only on the coast but with the great drought the farmers inland could no longer win (and lagoon fishing rose)"
Ministerial level	"It was catastrophic. People had to walk a lot for water, the crops were abandoned, and the cows had to climb into the hills (to graze beyond agreed limits). (Forest/grass) reserves … destroyed"
Regional leader	"Farms were abandoned; people were employed en masse in the government. Land … lost its fertility … erosion did the rest of the job. There is not enough water"
Island exporter	"Before 1974 we exported a lot of livestock to Mauritius … we lost 80% of our cattle in the drought"
Enforcement (marine)	"There was a (modernisation) boom in the 1970s. We started to build with basalt blocks and we de-rocked (the hills and terraces) to make roads and houses. This and deforestation set off land degradation. The sediment went into the sea, where it was trapped by the reef (hitting fishing)"
Ministerial level	"Dietary habits changed. We ate what we produced (but) after the drought we stopped, and imported rice came to replace the maize that we ate"
Government/donors	"I don't know if it is climate change but we see it everywhere—we are getting more and more extremes of weather …"
Enforcement	"The danger is that we do not slow the degradation of the environment and man's contribution. If not, Rodrigues will not be here in 75 years. Rodrigues will be a bare land"

Table 3
Summary of interviewees' perceptions relating to Rodrigues' social–ecological system in the 1970s in terms of changes in capitals—illustrated in Table 2 and expanded in Tables 4 and 5) (Abel et al., 2006). Capital changes are proposed in terms of collapse and recovery phases in Holling's Adaptive Cycle (Gunderson and Holling, 2002).

Principle change	Related capital	Mention (n = >5)
Farm/livestock decline	Social, human, natural	Lack of rules/tenure, loss of knowledge, soil loss and deforestation (erosion), diet change/food imports, pests, low trust, climate events/change
Fishery decline	Human, natural	Population rise, government incentives, increased efficiency, drought (farm decline), lack of trust (enforcement), loss of habitat, climate events/change
Water deficits	Social, natural	Emergency coastal drilling (drought), unregulated use, management, unequitable distribution, inefficiency, climate change
Dependence (economic)	Social, financial	Collapse in productive sectors, social security, government jobs, access to credit, emigration of skilled, rising political power in MIOM, ethnicity
Migration	Social, human, physical	Loss of educated/skilled, aging population, social problems, poor educational attainment, limited economy, transport links
Power shift	Social, human	Top-down culture, politicisation of issues, lack of trust at local and inter-island levels (Rodrigues with central government in MIOM), ethnic cultures

nothing. The animals had no water, grass, pasture – nothing. So cyclones are preferable to drought. At least they bring water."

Respondents' comments suggested long gaps between severe cycles of droughts and cyclones may have worked against the emergence of adaptive responses to limit degradation of ecosystem goods and services supporting the local economy:

"There were always big ones (cyclones) in the 1940s – 1943, '45, '46, '47 and then in 1947 the cyclones suddenly disappeared. You heard no more of them to the point you forgot about them. Then in 1959 we had a really strong one – and that brought Rodrigues to its knees!" (Old fisher/farmer)

5.2. Recovery

Interviewees' accounts indicate a collapse in livelihoods but also a failure in choice and implementation of policies that, from 1970s onwards, entrenched Rodrigues' rising dependence on capital inputs from higher scales (mostly MIOM and donors). Here we explore some of these in the context of polices most frequently raised in interviews:

5.3. Collapse of farming, rise of state sector jobs

Farm workers and others left the land due to drought during and after the 1970s to work on a part-time then full-time pensioned basis for the government, entrenching farm abandonment and creating dependency (Dupon, 1967; Beehary Panray, 2004):

"Before the drought people did not want to work for the (central MIOM) government. The effect of the drought is that the government hired almost everyone ... there was nothing to do. Agriculture suffered ... the people who went to work for the government were good farmers." (Fisher/farmer))

Agricultural output by 2000 was below 1970s levels, with land area cultivated falling from 1989 (1571 ha) to 2004 (173 ha).

Table 4
Summary of Rodrigues' proposed collapse during a 1970s drought, and factors influencing the nature and extent of its social–ecological recovery.

1. What caused the collapse?	2. What was the nature of proposed collapse?
Historical forest/soil degradation	Water shortage, over-pumping, water table pollution
Declining per capita land area	Crop and livestock loss
Limited crop range/poor practices	Destruction of forest/grazing reserves and terraces
Land lease system (open access)	Farm abandonment (food insecurity)
Reliance on rain-fed farming	Accelerated soil erosion/lagoon sedimentation
Political uncertainty/budget limits	Damaging pressure on marine resources—with repeated fishery enforcement failure
Poor education, external decisions	
Poor market prices (maize)	Emigration/brain drain
Climate variability, events	Gradual social fracture, enhanced mistrust
Lack of trust	Demand for local political power
3. Trends in collapse-recovery"	**4. Factors helping/hindering recovery**
Population stabilisation	New emigration routes, Creole community in Mauritius, cheap labour demand
Unemployment (dependence on external subsidy)	Farm reform failure, consumer culture, global shift to services (limits options for school failures), competing labour (Asia), dependence habit
Dependence (budget/state jobs)	Rising wealth in Mauritius boost wider economy (Lomé/Cotonou preferential trade with EEC, Mauritius Export Processing Zone), voter appeal (elections)
Shift towards tourism sector (rising natural resource requirement)	Global tourism trends, regional competition (inc. Mauritius), but air access bottleneck (near-monopoly), remoteness
Fishery expansion (lagoon and fishery degradation)	Politicisation, perverse incentives, rising tourism demand, shipping and refrigeration, limited livelihoods, drought impacts, poor credit in past
Livestock overstocking (land/forest degradation, rising water demand)	Continuing open access regime, market demand, donor policy, farmer view of cattle as "wealth store", taboos about cows in Mauritius (Hindu)
Farming pattern shift to valleys (water-needy table produce)	Donor projects, erosion//poor yields/water shortage on hillside, soil nutrient loss/salinity, table produce demand, tourism/healthy diet
Food import dependence/diet change (rice "invasion", fish)	Drought, underinvestment, youth disinterest, traditional farming, "lock-in" of land, pests/disease, maize production vs. rice import costs, fixed prices
Power shifting to autonomy	Island "difference", financial burden, unofficial networks (Catholic/cultural), rise of strong leader, identity politics, European/US/Papal visits, ethnic riots
Repeated policy failure	Capacity shortage, externally driven policy, mistrust, enforcement issues
Invasive tree cover	Fuel alternatives//building materials, reforestation effort, exotics burn less well
Producer to consumer culture	World trade (Lomé/WTO), Mauritius GDP, credit, government jobs, transport
Time/space compression	IDD, TV, faster/regular ship/air links, ties to Europe, globalisation

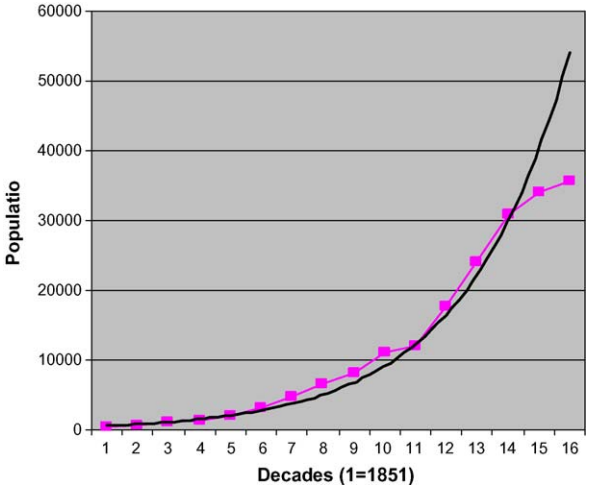

Fig. 4. Population growth by decade (1851–2000), with a post war stabilisation (decade 10: on dotted line) compared to the trend (solid line). This was followed by renewed exponential growth in the population from 1951 to 1981 (decades 11–13). Population stabilised (compared to the future trend) after a 1970s drought which accelerated emigration to MIOM and beyond.

Backyard agriculture expanded (uncertain area) but food was increasingly imported to replace local traditional crops. Cattle farming collapsed due to drought mortality and market shifts in MIOM, while grazing land shrunk due to housing and other uses. Farmers leaving the land recall selling anti-erosion terrace stones to builders. Such pressure was notable on a steep island with only 3.1% of "Good Agricultural" land (FAO, 1998a,b). Rodrigues population density of 351 km^2 is below that of MIOM (+600) but lower urbanisation and traditional farming means land pressure is high. Rodrigues growing transport links to MIOM and beyond are blamed for phytosanitary risks, not least to acclimatised crops with export potential.

(**Imports**) There was an invasion of rice … (from MIOM)

(**Subsidy**) To restart (farming after 1970s) incentives were … lacking. We have missed a generation

(**Culture**) (Youngsters say): "Me? I have been to school! I don't want to work the land"

(**Custom**) The problem is they (older farmers) are reluctant to change their ways of working

(**Practices**) Pests did not used to be (in Rodrigues) because … (of) seasonal crops (vs. year-round culture)

(**Genetic**) If we lose (acclimatised export) crops (chilli, red beans, limes) it will be a great loss (genetic)

5.3.1. *Perverse fishing incentives*

Of critical note to reef and fishery health, Rodriguans refer to damaging impacts of social security payments (Bad Weather Allowance—BWA) introduced in the 1980s to compensate fishermen for days when sea conditions were determined to be too rough, as measured by wind speeds in distant MIOM. Creole fishers are generally marginalised in Mauritius (Hollup, 2000) but different weather conditions in Rodriguans meant fishers using poor methods could still fish whilst collecting subsidies, providing a strong incentive to register as a full-time fisher. Numbers rose sharply from under 500 in the 1970s to 2069 registered in 1992, and a current estimate of 5000 or so with part-timers. BWA continued up to 2006, when cuts started with austerity budgets decided by central government in MIOM during a national economic reorientation towards services and perceptions of overfishing (Bunce et al., 2008):

> "The number of fishers went up considerably when the Bad Weather Allowance was introduced (1985). It raised the number of women from all corners of the island. It is paid from only 19 knots of wind, which is more common here than Mauritius. Many fishermen still fish when it is 25 knots, knowing they'll still be paid. They fish for the allowance!" (Former Minister for Rodrigues)

(**Limited livelihoods**) Cut the BWA in Mauritius and (fishers should) get another job—not in Rodrigues!

(**Unemployment**) Most people do not have jobs so they go to the sea, it is a political problem

(**Low conservation ethic**) It is hard for (Rodriguans) to accept rules (on the environment) … we don't see the need

(**Lack of taboo**, **rules**) … Not that kind of belief system that you see in the Pacific (island fishing communities)

(**Poor enforcement**) People are getting poorer … catch that (illegal fisher)? His children will die of hunger!

(**Enforcement**) Crooks fish for (fisheries guards) and they share the money

(**Open access**) The lagoon will decline. It's not the government that will make them stop (but low returns)

(**Politics**) Government priority is development … keep the (fishers) happy … it is a big, big electoral pool

(**Resistance**) … Recycle fishermen? (other jobs) There will be a lot of political issues over that! (MPA issue)

Five existing reserves with bans on seine net fishing were gazetted around Rodrigues in 1986 based on failed inshore reserves set in 1906, but they were never implemented. Plans for newer marine fisheries reserves and a large Marine Protected Area have been advanced since 2006, with hopes for related tourism income.

5.3.2. *Poor land and water management*

Over-pumping of coastal aquifers during the 1970s set the scene for later saltwater intrusion. Water networks were installed but management of water collection and distribution remained poor. Chronic shortages are normal rather than seasonal (FAO, 1998a,b), with demand far outstripping supply. A Rodriguan water riot in 1998 highlighted risks of shortages (Berthelot, 2002). A lack of water recharge to aquifers supplying 40% of Rodrigues demand is reported by officials.

> "The terracing was a good idea but the problem was that we lost our water. We cannot plant anything because of the droughts and it is getting worse … there is no work so the sea suffers" (Old fisher)

Water demand is estimated to be double the 5827 m^3/day supplied by public infrastructure in low periods of 2000, and 20,000 m^3/day is projected for 2020 when water stress due to climate change is expected to be acute in Africa. Desalination plants (2×2000 m^3/day) planned for emergencies may require expensive energy imports and power plants. Interviewees also reported how a lack of irrigation in droughts encouraged some farmers to fish, during then permanently after the 1970s drought. Farmers who became state employees held on to leases of good land (lock-in), while state ownership of land (>90%) limited opportunities for raising private capital. Land tenure and property rights remain ill-defined and overlapping, hindering cadastral assessments and resolution of open access resource problems to encourage farmers.

(**Water politics**) They (local leaders can use water (and land) as a political card—and they do (for coercion)

(**State land**) Land leasing (90% state-owned) is archaic, should be overturned. It has become a trap

(**Land laws**) Laws are in conflict. Who is responsible? There is a vicious circle turning!

(**Development limits**) A lot of land is leased—that has slowed up development (also stops outsiders buying up)

(**Open access**) ... Still a big problem between planters and farmers AND ... used to letting animals wander

5.3.3. Reforestation

Deforestation eased after the 1970s due to fibreglass boat-building (late 1980s), the use of concrete and, critically, liquid and gas fuel imports and electricity. Thorny acacia planted mid-drought onwards to stabilise soils and cut livestock roaming had a feedback loop of invading large areas of the island—with health, livestock, biodiversity and aesthetic impacts. Eucalyptus and other exotics (Kueffer and Mauremootoo, 2004) planted for what one forestry expert on the island described as a misguided attempt to "do something" to correct past deforestation similarly spread. Endemics are being introduced in small areas but trees still have to fenced into enclosures to protect them.

(**Commons**) The animals were a problem (saplings) ... (so we) fenced in the trees (not the animals)

(**Endemics**) The (quick-drying) endemic trees ... when you cut them down you can burn them straight away

5.3.4. Donor projects

As is common in small islands, responses to the drought and policy programmes afterwards were largely formulated and funded by outsiders from Mauritius and Europe (Baldacchino, 2002). A donor "Anti-Erosion Project" (1986–2004) built up productive sectors through land, irrigation, marketing and other initiatives (Anon., 2004). Farm production rose with credit, irrigation and farming in fertile valley bottoms. However, production was hampered by water deficits and poor storage and marketing. Erosion and agricultural decline continued, while the lagoon became more sedimented. French-styled fishing and farming cooperatives failed to revive primary and secondary sectors.

(**Deference**) The lack of self-esteem and confidence among Rodriguans in what they prefer plays heavily. Why do Rodriguans normally applaud and give value to foreigners?

(**Low capacity**) In all sectors you see someone heading who knows nothing about it

(**Low participation**) All projects from the outside do not work (examples). The project should be in collaboration with the people, with their own hearts in it. They should define strategy ... implement

(**Capacity**) People are not trained enough in (project) follow-up to focus attention and say "Stop!"

(**Poor enforcement**) You need trust. We are not there to use the baton without the carrot (MPA plans)

5.3.5. Inter-island power shift—rise of regional leader

An agent of change emerged during the drought. A charismatic ex-Catholic priest living atop the highest mountain rallied (1976) Rodriguans and raised their political profile (new Ministry for Rodrigues), delivering semi-autonomy by 2001. However, identity politics and cross-party resentments cooled inter-island relations before and afterwards. Rodriguans talk of their island as a nation or country, despite its impotence.

(**Island identity**) Rodrigues voted against independence ... think of themselves as Rodriguan, firstly!

(**Island mentality**) It is an island ... every family is an open book which you can read and turn the page

(**Top-down culture**) (Island leader had a) ... "Moses" leadership culture: "The priestly mentality (which said) "I am the boss. I am the man who tells you your destiny, plans (it). ... I am god's representative" (in Rodrigues)

(**Regional links**) (In MIOM) Hindus are ... majority so (Rodriguans) feel affinity with Reunion, Madagascar ... etc.

(**Regional links**) When they look to Reunion (France) ... it looks like they are by-passing Mauritian systems

(**Limited autonomy**) Before ... (MIOM) had a grip on Rodrigues. (Then) Mauritians realised Rodriguans are aware of their own power. This was a shock for Mauritians as there were fears of losing the island of Rodrigues

In what could be seen as a post-1970s recovery phase interviewees recounted many hindrances to effective policy formulation and implementation able to resolve Rodrigues problems, due to its local island mentality but also poor relations with MIOM.

(**Island mentality**) (Rodriguans) don't like rules ... if someone goes up the hierarchy we cut them down

(**Island mentality**) Everything is politicised. (Not) new that people (Rodriguans) cannot get together

(**Top-down decisions**) Ideas from lower committees get lost as they are taken higher ... people start to speak in French or English (problem of) "Big Men" ... people won't say what they think ... lose interest

(**Limited autonomy**) Before (autonomy) ... (MIOM) had a grip on Rodrigues. (Then) Mauritians realised Rodriguans are aware of their own power. This was a shock for Mauritians as there were fears of losing the island of Rodrigues

(**Inter-island policy limits**) Each time Mauritians come up with an idea, Rodriguans say "No!" ... ("cussedness")

(**Regional links**) When they look up to Reunion (French island) it looks like (Rodriguans) are by-passing Mauritius

5.3.6. Dependence

Rodrigues by 2006 was dependent on MIOM central government for around 90% of its annual budget (2005), with 67% for wages (2004/2005) (Clair, 2005). Fishers' BWA was cut in a 2006 austerity budget, prompting protests. Rodrigues figurehead of 30 years was mobbed and lost elections to the regional opposition in what was the island's first notable democratic transfer of power. Under new plans Rodrigues is viewed by MIOM as a more economically integrated export economy (fishing and farming) for supplying higher scales (MIOM's national food and tourism needs). However, Rodrigues has lost much of its landscape functions for farming (regulating water, nutrients and organic matter), with equivalent risks emerging in its reef lagoon fishery.

(**Dependence**) Rodrigues is like a sick child we are trying to keep alive next to Mauritius

(**Dependence**) ... Sustainability in the long-term is dim. We are 99% dependent on (Mauritius') hand-outs

(**Inter-island trust**) Mauritians gives things to Rodrigues reluctantly

(**Marginalisation**) Creoles are not at ease ... because they are the poorest in "Indian" Mauritius

(**Status/caste**) (Hindus and) even the Mauritian (Creoles) look down on (Rodriguans)!

(**Development**) Different history … people … realities. (We need to) develop in a way suited to Rodrigues

(**Regional ties**) Unity makes strength … why not … a (regional small island) federal system?

Natural hazards were seen by one official in MIOM in terms related to natural hazards being positive for bridging perceived divisions between Rodrigues and MIOM:

> (Power) Yeah, nation-building. I think it could be a common enemy or a very big cyclone … it would be a good thing to have a major calamity … something really strong, to get people to set aside their differences (MIOM government official with reference to Rodrigues)

5.3.7. Population shifts

Outward migration accounts for high percentages (>50%) of natural increase in the population (CSO, 2005). The Rodriguan population resident in MIOM is estimated to be as large as Rodrigues'. Many still depend on natural resources. Riots in 1999 underlined rising ethnic tensions in MIOM (Rodriguans/other Creoles and Hindus) and other social problems. Remittances sent back to Rodrigues are unclear, but seem low.

(**Development**) Fishing … tourism … unless we engage more, more people will leave (Rodrigues island)

(**Migration**) … High (Rodriguan) birth rate … brain drain … island never develops. It is a vicious circle

(**Birth rate high**) But the (Rodriguan) population never seems to increase (except in MIOM)

(**Buffer**) We are the same state (Mauritius), but who knows! There could be migration controls if they think too many (Rodriguan) people are coming to (MIOM) – (unemployment, crime, social security demands)

(**Crowding**) You've got Mauritians who can come and buy land and invest AND Rich people (Mauritians) … build a second home. What would Rodriguans do except go to Mauritius? (State land as "protection" for local residents)

5.3.8. Tourism recovery?

Donors and officials view tourism as a local market creation tool for farming and fishing sectors, but the sector has remained subject to investment risk (hotel closures in slumps), high operating costs, poor skills base, local scepticism, irregular tourist flows and remoteness affecting air ticket prices and outsider control. Tourism expanded after the 1970s but it lagged far behind MIOM's boom. Infrastructure remained basic, and Environmental Impact Assessments are cursory (Ramessur, 2003; Ramjeawon and Beadassy, 2004). Tourism slumped in Rodrigues after 2000. It's future expansion is linked to agriculture, new off-lagoon fishing and the new marine reserves and Marine Protected Areas whose implementation is underway (Gell, 2005; UNDP, 2006).

5.4. Summary—a collapse and recovery?

Rodrigues appears to have entered the 1970s with limited social, human and natural capital, and low levels of physical and financial capital. Based on our interviews we considered that a collapse (Ω) phase may have begun in the 1970s, catalysed by a severe drought, of which impacts were exacerbated by prior ecosystem degradation (Table 4). The island collapse or "release"

Table 5
Proposed slow-changing variables driving island change, their possible interactions with faster-moving variables to produce undesirable impacts, and (cited) relevant literature.

Slow-changing variable	Interacting with faster variable	Impact
Local	Population rise and land pressure	Open access resource degradation (Buck, 1989)
Land tenure (lease) system	Regional food demand—population/tourism Sporadic drought/cyclone severity (Payet and Agricole, 2006) Rising state sector employment after drought	Farm abandonment and food insecurity Loss of knowledge/migration "Lock-in" of usable land (reduced area) Reduced economic options (tourism)
Local	Crop pests and disease (with natural hazards and rising transport links) (Holling, 1994)	Food import dependence
Soil nutrient loss	Livestock increase after 1970s slump	Pollution from rising chemical inputs Soil erosion//damage to lagoon fishery (Fabricius, 2005)
Local/inter-island	Marginalisation of black Creoles/fishers (Hollup, 2000; Laville, 2000)	Lack of strategic thinking/initiative
Low trust	Economic decline since drought Arrival of divisive identity politics in Rodrigues Decreasing isolation (transport/communications)	Economic dependence/marginalisation Migration/ethnic tension in Mauritius (UN, 2001) Regional autonomy Resource degradation
Local/global	Aquifer mismanagement and possible pollution	Declining food security (Sanchez, 2000)
Climate variability	Coastal saltwater intrusion Impoverished soils (de Blic, 1986) Biodiversity loss (Strahm, 1989; Bunce et al., 2008) Loss of farming/fishing expertise (Dupon, 1967)	Water desalination risks to lagoon (Raventos et al., 2006) Rising disease in biota (Harvell et al., 2002) Extension of land degradation to lagoon Ecosystem decline/invasive spp. (Urban et al., 2000; Gell, 2005) Constrained development/dependence (Munasinghe, 2001)
Regional/global	Low educational attainment (Bunwaree, 2001)	Limited economy/Import dependence
Trade patterns/rules	Improving shipping/air links Market competition within Indian Ocean region New communicable disease (people) (Julvez and Ragavoodoo, 1998; Mauritius, 2004)	Consumer debt/unaffordable credit (North-Coombes, 1971; KPMG, 2006) Unpredictable local investment/FDI (Armstrong and Read, 2002) Unemployment/migration to Mauritius Aging population/social breakdown (UNDP, 2003)

phase is related here in terms of a loss of capital large enough to require both the rebuilding of capital through self-organisation from within the social–ecological system and through or an injection of capital from higher scales – in this case the larger and distant MIOM (Abel et al., 2006).

We propose underlying slow variables which may have contributed to this loss through their interactions with faster variables, ensuring that severe impacts (Table 5) of natural hazards in the 1970s lasted into later decades (recovery phase α). New policies do not appear to have ended degradation, which instead extended out to sea after the 1970s.

6. Discussion

6.1. Adaptive cycles and downward spirals

We set out to provide a case study relating to a research gap on how a society reorganises following a crisis (Abel et al., 2006). To do this we aimed to identify, in a remote small island, two phases of Holling's (four-stage) adaptive cycle—collapse and recovery. Compared to some other studies (Walker et al., 2002; Seixas and Berkes, 2003; Abel et al., 2006) we found it hard to identify adaptive cycles repeating themselves over history, whilst recognising periods of accentuated degradation and missed opportunities for policy action (Cocks, 2003). Turning instead to our interviews covering recent decades, and for which we had access to better data, including our findings, we still propose only one conceivable recent collapse catalysed by a natural hazard (drought) in the 1970s. Even for this we argue that collapse appears to have continued long after the drought, with a recovery running in parallel rather than afterwards. It may be that recovery occurs over longer timeframes than we considered. Perhaps collapse and recovery do run in parallel, with either advancing, receding or petering out without necessarily following an adaptive sequence. In Rodrigues, this may have involved a downward staircase of declining capitals without any compensating growth and conservation phases. The question is further complicated by the issue of where to set spatial and temporal limits to a social and ecological system under study. We set ours at regional island level for reasons we explain, but the appropriate level could well be different—and there was a lack of data in the natural system that confounds bold statements as to change in social–ecological state at whatever scale is accepted. We did not fully account for the complexity this might imply (Cumming, 2005; Jianguo et al., 2007; Karunanithi et al., 2008), including the possibility of alternative social domains for which the dynamics of social and ecological components are hard to consider in tandem (Walker et al., 2007). Whatever the case, the lack of clear delineation in practical application between phases show as distinct in Holling's Adaptive Cycle raises several important questions over its usefulness. Could the Adaptive Cycle be simply losing some of its descriptive powers as rapid global change redefines temporal and spatial scales, (Cumming, 2005; Young et al., 2006a,b; Janssen et al., 2007; Bohensky, 2008), or are we witnessing a more onerous parable of regional up to global unsustainability, as Diamond (2005) suggests? Overall, we support a notion that social–ecological systems may get stuck in a post-collapse recovery, in which no structure emerges.

6.2. Cross-scale issues

Overall, our results support the view that during collapse and reorganisation a system is at its most vulnerable to change (Walker et al., 2007), as linkages between lower and higher scales are accentuated. Cross-scale connectivity (flows of people, goods, information, money, power) emerged in our study as a critical component of island social and ecological resilience (Bayliss-Smith et al., 1988; Bertram, 2006; Janssen et al., 2006a,b, 2007). Drought degraded social and natural capital, arguably cutting the diversity of livelihood responses to future disturbance (Marschke and Berkes, 2006). Migration to MIOM may have been an indicator of breakdown of local social resilience at the lower scale of Rodrigues (Adger, 2000; Locke et al., 2000; Hamilton et al., 2004). Economic subsidisation down-scale from MIOM and donors to Rodrigues may have accentuated Rodrigues failure or inability to self-organise (Abel et al., 2006), and in turn its capacity to adapt to future social–ecological disturbance. Although connectivity may be a source of resilience, cross-scale stressors are expected to rise in frequency and intensity, while remaining largely beyond island-level control (Hughes et al., 2003; Young et al., 2006a,b; Cherian, 2007; Few, 2007; McClanahan et al., 2007). There is a risk of collapse in marginal islands being passed up successively higher scales to aggregate in global fragility. For example, Rodrigues' corals are among the most pristine in the western Indian Ocean, which make a key contribution to the global carbon cycle regulating climate, but their future is not guaranteed (Rees et al., 2005; McClanahan et al., 2007).

6.3. Island limits

Rodrigues for long appeared to remain a marginal "sister" island (van Beukering et al., 2007) lacking financial support to adapt to change. It's relations with MIOM, the next highest scale in our study, suggest a small island tendency toward multi-insularity – or ethnic communities isolating themselves – risking the promoting of quasi-nationalisms within administrative units of island states (Baldacchino, 2002). These and other common island challenges (Baldacchino, 2006; Bertram, 2006) were raised in our study in relation to MIOM and Rodrigues in terms of talk of an end to semi-autonomy or a bid for full independence (Eriksen, 1994; Miles, 1999; Hollup, 2000; UN, 2001; Neumann, 2004; Read, 2004; Baldacchino, 2006; Bertram, 2004). The point is that adaptive management may fall if societies do not share a viable long-term vision toward which pragmatic steps may be taken and carefully monitored. It has been said that Rodrigues for long related to MIOM in a similar pattern to Mauritius past colonial relationship to the British Empire, "producing primary goods and buying manufactured goods". Protecting Rodrigues' natural resource base may not have been important to enough people with influence to stop a downward spiral in its state. Shifting baselines among scientists generally (Pauly, 1995), and fisher-farmers in Rodrigues (Bunce et al., 2008), may also be a factor accounting for poor official response to degradation in Rodrigues over centuries.

6.4. Policy implications

Degraded and vulnerable social–ecological systems such as Rodrigues island may be said to have lost resilience (Folke, 2006), and adaptability to future disturbance (Adger et al., 2005b; Folke et al., 2005). The relationship between vulnerability, resilience and sustainable development in such islands needs to be better understood (Jianguo et al., 2007) and managed with typical island livelihoods or new ones in mind (Becken, 2005; Reid and Vogel, 2006; Coulthard, 2008; Tuler et al., 2008). Looking to the future (r and K in the adaptive cycle), Rodriguan perceptions and limited secondary data suggest that from a vulnerability perspective alone Rodrigues' intrinsic exposure to risk is already similar to many island states (UN, 1994, 2005), including for climate change (Barnett and Adger, 2003). Such islands may face hard choices in terms of the levels or population and development they can support, for example in terms of the survival of coral ecosystems supplying critical goods and services (Sheppard, 2002, 2006). Low lying atolls may become

uninhabitable (Pernetta, 1992; Barnett and Adger, 2003). Potable water is already a critical issues provoking user conflict and questions of equity in distribution (Stonich, 1998; Pigram, 2001). Our study suggests that selecting appropriate policies and applying them at optimal scale has critical implications for island adaptation to disturbance, including possible impacts of climate change (Adger et al., 2005a; Urwin and Jordan, 2008). Regional self-autonomy perhaps gives Rodrigues a new start but as in other comparable twin-island systems it faces considerable policy challenges (Brown et al., 2001; Adger et al., 2003, 2006). Ultimately, islands once resilient to social and ecological disturbance may not be so in future (Bayliss-Smith et al., 1988; Barnett and Adger, 2003; Hamilton et al., 2004; Diamond, 2005). Future resilience may lie at different social and/or ecological scales, with political, economic and cultural ramifications for conserving locally critical ecosystem goods and services. In remote islands governed from higher scales perceptions of legitimacy and equity may critically determine the outcomes in terms of adaptation (Thomas and Twyman, 2005). With respect to reliance on Marine Protected Areas planned for development in Rodrigues there are cautionary tales (McClanahan, 1999; McClanahan et al., 2006).

6.5. Study limitations

The historical nature of our study and a generally data-poor study site meant we relied heavily for our recent findings on judgement, intuition and the coherence of stories (Abel et al., 2006). The temporary and shifting roles of the many interviewees in our view also meant that knowledge and roles often did not coincide or prove comparable for more statistical analysis. We accept that this limits conventional disproof of hypothesis and that other explanations are possible. A comparison of user groups within Rodrigues and between Rodrigues and MIOM would be an interesting addition to refine our study (Gelcich et al., 2005). Recent concepts for bridging gaps between research disciplines (Füssel, 2006) may also help in the task of answering the many remaining questions relevant to building social–ecological resilience in small islands with close land–sea interactions (Walker et al., 2007).

7. Conclusions

Understanding past social–ecological responses to the impacts of natural hazards holds useful clues to fostering island adaptation to expected global environmental change. We conclude that as global environmental change redefines temporary and spatial scales the policy usefulness of models such as the adaptive cycle may be limited. More interdisciplinary research could help develop new ways of capturing the complexity of how social–ecological systems may renew, re-organise and achieve resilient development across multiple scales as encountered in this twin-island case study site.

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