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Social-ecological systems analysis of a restoration project following rutile mining in humid West Africa

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ABSTRACT

This paper details a social-ecological systems analysis of a restoration project using panarchy theory. The project aimed to develop a practical reclamation methodology involving both socially and ecologically sustainable techniques. We tested a decentralised business initiative model whereby local people provided compost to a large international titanium oxide mining company (Sierra Rutile Limited) for payment. Ecologically the project was successful in restoring a pioneer herb layer to mining spoil but socially the model tested was unsuccessful and not adopted by the mining company (SRL). We argue that a fuller understanding of the position of the social and ecological elements of the project on their adaptive cycles at the start of the project may have alerted the project team to potential problems.

Keyword: adaptive cycle; panarchy; restoration ecology; titanium oxide

INTRODUCTION

Mining constitutes a major anthropogenic land-use change involving complex interactions between social, political, ecological and economic factors (Perrow and Davy 2002). Several studies have shown the value of exploring land-use change in the context of complex adaptive socioeconomic and ecological systems (Allison & Hobbs 2004; Grotts, 2007; Zaccarelli et al. 2008). The aim of this paper is to report the potential of system analysis to aid researchers and practitioners when conducting restoration activities.

The panarchy theoretical framework (Gunderson and Holling 2002) is helpful in the understanding of complex social and ecological systems and was used extensively in this study. The adaptive cycle Holling and co-workers propose with the four phases: conservation (K), release (Ω), reorganisation (α) and exploitation (r); combined into a three dimensional mobius strip provides a framework to explore ecological and social cycles (Gunderson and Holling 2002). Each phase of those cycles creates the condition for the next phase. A pattern of two phases of growth, followed by two phases of reorganization are

proposed. The first two (r and K) form a familiar, slow, fairly predictable pattern of growth called the “forward loop”; the second two (Ω and α) constitute a less familiar, unpredictable, and, in the case of mining ecosystems, more rapid “back loop” of reorganization (see Figure 8 for example).

We have used a restoration project at Sierra Rutile Limited (SRL), Bonthe District, Sierra Leone as a test case to evaluate this approach. We will document the journey taken and the actors involved in an integrated restoration project funded by the Darwin Initiative Fund entitled ‘Novel and practical conservation strategies following mining in Sierra Leone’. The shorthand project title used in Sierra Leone is DARWIN standing for **D**arwin **A**nd **R**utile **W**orking with **I**ndigenous **N**eighbours. The short hand version of the project title will be used through out this paper.

Following a brief description of the human-environment systems present in the mining community and the aims of the DARWIN project the position of the various components within adaptive cycles will be illustrated. The alignment of adaptive cycles during the project implementation phase and the influence of this on the outcome of the project after 2 years will be discussed.

SIERRA RUTILE LIMITED (SRL)

The project focused on the mining concession area awarded to Sierra Rutile Limited (SRL). This company has been actively mining rutile in the south western coastal area of Sierra Leone (Figure 1) since 1979. The economic civil war (1991-2002) resulted in the speedy suspension of the mining operations in 1995 when rebels attacked. The mining operations recommenced in 2004 when the political condition in Sierra Leone stabilised (ref Knight Piésold report).

There are rich rutile deposits in the SRL concession area and the company has employed both wet and dry mining techniques in the past. Since 2004 wet mining i.e. dredge mining, has been the major mining activity of the company. Dredging is inherently ecologically destructive, destroying soil structure and leaving large ponds in the landscape. The mining operation inevitably takes agricultural land out of production for the local population. The company pay a ‘surface rent’ in the order of £11 ha^{-1} which is distributed xx% to the land owner, xx% to the district chief and xx% to the national government. Following the war the national government agreed SRL project plans which required for the construction of two additional ponds at Lanti South and Gbeni and the expansion of the existing pond at Lanti North. It was expected that these initiatives would require 990 hectares of land to be converted from agricultural to industrial use during the current operational phase. Approximately 70% of this land area was allocated for reclamation to an agricultural post-mining land use. The remaining 30% was planned to be left as a fishery after mining is completed.

The total estimated aerial extent of land disturbed by SRL activities prior to the current initiatives was estimated at 3,675 hectares (Knight Piésold report).

Reasonably foreseeable future development plans estimated an additional 7,500 hectares. As such, rutile mining in the project region on a cumulative basis was thought to involve in the order of 13,000 hectares of land (Knight Piésold report).

The local communities in the project area typically rely on subsistence-level slash and burn agricultural practices to provide their household food and income. Immigration of hopeful employees to the area exacerbated an already significant land pressure problem.

SRL recognize the need to implement and support initiatives aimed at improving the living conditions of the local communities in a sustainable way. To this end, SRL had previously formed partnerships and supported programs implemented by non-governmental organizations (NGOs) such as CARE, as well as directly organizing and implementing programs in cooperation with local communities (Knight Piésold report). Despite their best efforts relations with the local community, which did not derive an income from SRL, was poor at the start of the DARWIN project. One of the main grievances reported to the project partners was the lack of successful ecological restoration of the land already mined and lack of income from supporting services (e.g. food purchased) from the local community (Dick et IUCN report 2005).

SRL commenced ecological restoration activities in 1990. The horticultural consultant (Abdual Hassen King *pers. comm.*) reported that they planted commercial crops; coconut (9.3 ha), cashew nuts (16.2 ha) and mixture of cashew and acacia species (5.7 ha) on the worst disturbed land (sand tailing). The lesser disturbed area were planted with oil palm (5.7 ha) and mangos (1.2 acres). The standard method was 2-3 meter spacing for fruits trees and 0.5 m spacing for acacia woodlot plantations. The planting hole was filled with topsoil prior to planting the seedlings to encourage establishment. These plantings were tended and the cashew started to produce fruit in 1994/5. (Abdual Hassen King *pers. comm*.) When the rebels attacked in 1995 the sites were abandoned. Natural successional vegetation had not recovered on these planted areas after ~15 years when the DARWIN project commenced, partly due to annual fires started by local people (coconut, cashew nuts and palm oil) and partly because the woodlot species planted are aggressive pioneer acacia species which quickly shades out competing herbs or are exotic Eucalyptus species which produced very slow degrading litter. It was recognised that the revegetation of mine spoil was not delivering the landscape the local people required i.e. agricultural (Figure 2).

When mining operations recommenced in 2004 an Environmental and Social Action Plan (ESAP) was prepared by Knight Piésold Consulting (Knight Piésold report). The ESAP defined ‘the mitigation, management, monitoring, and institutional measures to eliminate, offset, or reduce the environmental and social impacts of SRL activates to acceptable levels’. The company has been attempting to fulfil the aspirations contained in that document. One result was to embrace the international research project which aimed to develop practical methods for land reclamation following mining in developing

countries that both conserve biodiversity and enhance community livelihoods – the DARWIN project (Dick et al 2006 Initial proposal).

DARWIN PROJECT

The focus of the project was to integrate current scientific information with local knowledge through a partnership of 10 groups; an academic research institute (Centre for Ecology and Hydrology CEH), and an independent consultant (Mind the Gap) in the UK, a Sierra Leonean NGO (Environmental Foundation for Africa), an international NGO (Conservation International CI) two Sierra Leone universities (Fourah Bay College (FBC) and Njala University (NU)) and the mining company Sierra Rutile Limited (SRL). In addition the initial proposal planned to work with three local communities in the mining area (i.e. 3 villages).

The project sought to pilot methods for practical reclamation, conservation and sustainable livelihood options in the SRL mining area. The project partners were sensitive to national government policy. The two pillars of the Natural Resource Management Policy of the Government of Sierra Leone in 2006 was to promote the rational and sustainable use of natural resources thereby protecting them from further damage; and to rehabilitate those areas of the country that were affected by severe vegetation degradation and soil erosion. In addition the National Biodiversity Strategy Action Plan (NBSAP) for Sierra Leone (reference) encourages an integrated approach to the use of land in Sierra Leone. Thus, through testing various schemes for local, rural-led restoration and emphasising appropriate payment and income generation models, the DARWIN project sought to directly contribute to the implementation of government policy.

A specific objective of the project was to test a decentralised business initiative and to ground test the approach by planting demonstration plots for the reclamation of degraded mining sites. This proposal led from other projects involving several of the same actors (Dick IUCN report, Dick Darwin pre-proposal report; Authors final IUCN report).

The following section briefly outlines the chronological sequence of events in the first two years of the project (Figure 3). The project commenced in November 2006. During a two week period a 15 person DARWIN project team consisting of 1-5 representatives of each of the partners (Dick et al. 2006 initial report) visited the mining site. The over arching management principle of the project was the participation of all parties. An initial workshop was held to explain the aims of the project to the communities and SRL staff. Twelve villages were represented at the initial meeting although only three were anticipated in the original project proposal. During the initial meeting all present expressed a desire to be involved in the project and it was decided to allow all 12 villages to participate in the initial stages of the project as it was felt unlikely that they would all actively produce compost or seedling and ‘natural waste’ would occur. With hindsight this was a mistake and number of people participating in the project exasperated the problems which followed.

In order to understand the relationships between the various stakeholders in the mining community and wider a field a network diagram was created and modified in participatory multi-stakeholder meetings at the start of the project (Figure 4). The diagram served to illustrate the inter-connectiveness of the local communities and the mining company around the mining area and in the wider country and global communities.

The proposal to initiate a market in compost and seedlings was welcomed by the community representatives at the initial workshop. The rationale of the decentralised business initiative was explained to the community representatives stressing as in all business arrangements the seller would need to be satisfied with the price and the buyer satisfied with the product. The villagers requested training in compost production so they could decide if they wished to enter into agreements with SRL to produce compost. Four training and experience sharing workshops were held attended by over 250 local villagers (Karium et al 2006). During the workshops the villagers were surveyed as to their views on the price they wished to be paid for compost and the plant species they thought would grow in the experimental demonstration plots. Over 20 plant species were suggested with around half being commercial food crops such as *Zea mais, Cocos nucifera, Elaeis guineensis and Cumunis sativus.* The price the villagers hoped to receive for compost ranged from $1 to $13 for a 34 cm bucket.

A further meeting was held with SRL representatives and an experimental design agreed. The financial implication of restoration activities was fully recognized by all present. An experimental design was agreed which was essentially 0.25 ha plots comprising 4 treatments; ± mulch spread over the surface and ± compost in planting holes of 18 inches by 18 inches. The plots would be spread over the three soil types identified – white sand, brown sand and lateritic soil. While the DARWIN team wished to test the experimental treatment of compost spread rather than mulch spread, cost implications forbade this option.

It was estimated that the 0.25 ha plots would cost between $1,200 and $3,500 to establish depending on the price of compost, mulch and seedlings agreed between the company and the village communities (excluding transport costs and ground contouring). It was estimated therefore that the cost of the 16 plots would range between $19,000 and $55,000. It was recognised that this was not a commercial rate for restoration but it was thought by all parties that economy of scale in future years would reduce costs.

In January 2007 DARWIN team members again visited the mining community and discussed compost quality (Wadsworth 2007) and also conduct workshops on seedling production. In order to foster relationships between villagers and SRL staff a ‘Skills Training for Conflict Transformation and Partnership Building’ workshop was held in May 2007 attended by ?number? (Jones 2007).

A six month review of the project activities was conducted in May 2007 where the quantity and quality of the compost and seedlings were assessed.

Sufficient good quality compost was found to be available to plant the experimental demonstration plots so the villagers were commended for their work and it was made clear that no new pits should be started (Dick et al 2007).

Representatives of the DARWIN team were present as observers at the meeting between the local communities and SRL to discuss and agree the price of compost and seedlings in June 2007 (Wadsworth 2007). Each community sent 6 representatives who were authorized to negotiate a price. Centralized negotiations meant that all communities were aware of what everyone else was thinking during the negation process. The price was amicably set at 10,000 leones for a 34 cm diameter bucket ($? ~£2).

Project staff were present when the first demonstration plots were planted to assist SRL staff (Wadsworth June 2007). However, the implementation of compost collection for the remaining plots was chaotic with villagers demanding payment for poor quality compost (containing glass plastic and other rubbish or augmented with soil). Despite a warning from the DARWIN team member on site SRL staff continued to purchase the poor quality compost. Villagers fearing that their compost would not be accepted by SRL started to demand that the company collect from their village and produce payment immediately. They removed the compost from the pits and stockpiled the compost then demanded the compost was removed as it was a health hazard for the children. SRL staff were over whelmed by the villagers and appear to have paid the loudest villagers first. In total compost was collected from 9 villages (Table 1) and total of Le 317,090,000 was paid (equivalent to £ and $ at that time). The purchase of additional compost allowed SRL to top dress plots with compost rather than simply use the compost to fill in tree planting holes.

In total, SRL reported that sixteen, 0.25 ha plots cost the company $150,000 which was paid to 9 villages. Three villagers received no payment and were left with the compost (Table 1).

For the illustrative purposes of this paper we will report only the results of the compost spread treatment on the sand tailing (Lanti North). The full experiment is reported by (see University reports). The compost spread was very successful producing both a herb and tree layer. Four moths after planting 16 volunteer species were recorded on the two replicate compost spread treated plots in Lanti North site (Table 2.) While the control plots contained only a few native species predominantly, ?????. The crop species growing in the composted treated plots reflects the poor quality compost i.e. the compost had not reached sufficiently high temperatures to kill the seed bank. When the plots were assess in April 2008 (Karim and Okoni-Williams 2008) the plots treated with compost spread showed excellent (50% - 90%) natural plant growth cover. Over 20 species of plants were seen.
Below ground fauna biodiversity also increased under the compost spread treatment.

In general the compost treated plots have continued to increase in terms of species diversity and complexity of ecosystem function (Figure 2)

SYSTEM ANALYSIS

Although the DARWIN project team had worked together on a previous project in the region a formal systems analysis examining the social and ecological components of the mining concession was not fully conducted. Conceptual models are recognised as representations of our present and past understanding of the overall system of interest and are an important first step in general systemic analysis (Walker et al. 2002; Allison and Hobbs 2004). The narrative above, combined with the principles of panarchy theory, has been used to identify the important causal relationships and structure of the system encountered by the DARWIN project during the first two years of the project.

Social-ecological hierarchies

The social and ecological hierarchies in the study area are semi-autonomous. As can been seen in Figure 5 the vegetative hierarchy forms a relatively linear pattern along a log time vs space continuum. The social hierarchy however while linear on the space axis is almost a constant on the time axis. The chiefdom system operates on the time step of 20-50 years (Chiefs are appointed for life) while the national and district governments are elected for 4 year periods. During the first two years of the project there was regular turn over of senior staff at SRL (3 chief executives, 2 heads of department.)

Adaptive cycles

The position of the ecological state of the mining concession and the social interactions of local inhabitants of the ecosystem (SRL personnel and local people) show the lack of synchrony prior to the DARWIN project commencing (Figure 6).

Prior to the start of the mining operation (1979) both the civil society and the ecological environment of the area were in the relatively stable conservation (K) phase. Although the local people practiced slash and burn agriculture which at a local scale pushed the vegetation from the K phase along the backwards loop from release (Ω) and reorganisation (α) and then onwards to the renewal phase (r) the ground area was relatively small and it recovered usually on a 10-20 year cycle (REFS?). Similarly the social adaptive cycle went though a full adaptive cycle periodically at local household and village scales but at the level of the mining concession was relatively stable.

When SRL mining company commenced operations in 1979 the ecological and social destruction was significant (Figure 6).

The rehabilitation efforts did not significantly revegetated the sand tailings left following dredging (less than 100 ha actively rehabilitated). The soil and seed bank were so badly degraded following mining that natural regeneration was

minimal. Through the war when mining stopped the destruction of the ecosystem ceased but there was little recovery of vegetation.

The social adaptive cycle at the scale of the mining concession was also severely disrupted by the activities of the mining operation in 1979. There was a period over several years prior to the outbreak of war when a huge influx of indigenous and foreign workers congregated at the mining site for employment. This created opportunities at the individual scale and severely disrupted the previous relatively stable power and patronage systems. The invasion of the rebels to the mining concession in 1995 was a stochastic event external to the local social cycle (although arguably strongly influenced by the presence of large commercial mining operations in the country) which caused a collapse in the social adaptive cycle of the citizens of the mining concession. Many fled the area to Freetown and some abandoned the country completely.

Following the end of the war the local people returned to the area and mining operations commenced in 2004. Civil society on one level then entered a renewal phase and started the climb along the 'front loop' of the adaptive cycle which is recognised to be more predictable as it develops (Holling 2001). There were however a need to re-establish the power and patronage systems and therefore the social adaptive cycle of the mining concession was yet to fully enter the renewal phase with significant elements still in the α reorganisation phase.

The mining company had only recommenced work in the area two years before the DARWIN project idea was suggested (Dick IUCN project). The DARWIN project therefore entered the panarchy cycle when the SRL and the wider civic society adaptive cycles were in this α reorganisation phase. Panarchy theory suggests that the 'back loop' of the adaptive cycle from Ω to α from which the communities and SRL had just emerged is inherently unpredictable and highly uncertain. This phase however does maximise the opportunity for change. For the latter reason we would argue that the DARWIN project chose a good time to approach SRL and the communities with the decentralised business initiative to sub-contract compost and seedling production to the local communities as they proved receptive to the idea.

Analysing the relationship between the adaptive cycles of the department within SRL responsible for restoration (Healthy, Safety and Environment - HSE) and the individuals reveals panarchical connections (Figure 7). The three cycles are interconnected and follow the concept of the faster cycle being at the lower level of the individual with the slowest adaptive cycle at the top being the mining company in this instance (Holling 2004). The HSE department was vulnerable to the influence of the high slower cycle above and the faster cycle of the individual below because it had not yet progressed to the more stable K phase of the adaptive cycle; the majority of the personnel had only been employed for less than 2 years and many aspects of their work were still formulating. In addition the restoration activities were secondary to the more institutionally important business of rutile extraction. It is well

established in panarchy theory that the faster lower cycle can trigger changes in the higher cycle which we believe occurred through the strong representation of the villagers during the compost collection in May-June 2008 (Figure 3). The personel of the HSE department were also venerable to the infleunce of the higher level. This resulted in senior managment decideding that following the large expense on compost in 2007 to revert to controlling all restoration activities 'in house' (Figure 7).

A fuller understanding of the position of indiviudals, communities and SRL departments within their own adaptive cycles during the first two years of the DARWIN project is relatively easy with hindsight but was not so apparent to the project team at the start of the project. Effectively the society was traumatized by social disruption and post war conflict to the point that cultural cohesion and adaptive abilities were severely under mined. In such a situation, the individual members of the society would be able to depend only on themselves and perhaps their immediate family members. This resulted in the rush to secure payment for compost by individuals loosely bound at the community level and a lack of collective strength in the HSE department.

In contrast to the social adaptive cycles described above the project positively advanced the ecological adaptive cycle of the mined area in a relatively stable practicable manner (Figure 8). At the start of the DARWIN project the ecosystem was effected by mining and can be consider to be in the Ω - collapse phase (Nov 2006). The addition of village produced compost (June 2007) which had not been sufficiently heated to destroy the seed bank resulted in many species growing and a period of reorganisation of species assemblages (α phase). By November 2008 when annual crop plants were eliminated due to lack of seed but hardy perennials and wind blown annuals grew, the species assemblages resembled a natural pioneer community and the ecological adaptive cycle of the experimental plots was entering the slow, fairly predictable pattern of growth from pioneer vegetation towards climax vegetation. It is too early to say if the herb pioneer vegetation present on the site in Nov 2008 will eventually mature to allow the desired agricultural post-mining land use sought by both local villagers and SRL officials but the signs are hopeful.

CONCLUSION

A growing body of literature has identified the social perspectives involved with sustainable land management (Gill 1996, Barr 2000, Cary 2000), and the cultural and political perspectives (Brewer 1986, Cary et al. 2002), which all emphasize the need for research to embrace a transdisciplinary approach in which social and ecological systems are treated as a single coupled and dynamically complex system (Gunderson and Pritchard 2002).

The DAWIN project reported here was conducted on an experimental scale and has successfully started to restored the land with an increase in number of native herbs and soil insects (refs) following rutile mining. However the restoration effort was not sustainable because the social dimension of the project was unsuccessful. We argue that a fuller understanding of the

interactions between the civil society and SRL officials would have altered the project team to the potential dangers of the maladaptive aspects of the social players. Written contracts suggested by the team were not favoured by either villagers or SRL personnel which it has been argued would have avoided the problems detailed within this paper. However, following this analysis it is doubtful if that approach would have been sufficiently robust to avert the problem of individual hedonism.

ACKNOWLEDGEMENTS

A great many people have contributed to the knowledge and analysis contained in the paper. The authors have consulted widely amongst villagers, mining staff and other Sierra Leonine's both in the mining concession area and wider a field. Of particular note are all the people directly involved in the DARWIN project including [include people not named as authors] …….

LITERATURE CITED

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Table 1. Quantity of compost and monies paid by SRL to 10 villages for compost production (exchange rate was Le3000 = $1).

Village	No. of community pits prepared	No. of community Harvested	Number of buckets	Total Amounts paid
Kpetema	6	3	2030	Le 20,300,000
Ndedemoya	4	4	2460	Le 24,600,000
Yangatoke	4	4	4340	Le 43,400,000
Gbonjeima	4	4	4040	Le 40,400,000
Foinda	4	4	6193	Le 61,930,000
Mokaba	2	2	1800	Le 18,000,000
Semabu	2	2	815	Le 8,150,000
Gbangbama	4	4	2335	Le 23,350,000
Bamba	4	4	6146	Le 61,460,000
Madina	2	2	1550	Le 15,500,000
Total			**31709**	**Le 317090000**

Note Three villages Lungi, Juntiola and Gagama produced over 70 private pits

Table 2. Volunteer species recorded in September 2007 in the two replicate experimental plots treated in June 2007 with ?? cm compost top spread at SRL, Sierra Leone.

Local name	Scientific name
Cow pea	
Cocoa yam	
Potulaka	
Tomato	
Jacato	
Pepper	
Crain crain	
Shokoto yokoto	
Okra	
Oil palm	
Rice	
Potato	
Bennie	
Pompkin	
Lagos bologie	
Wild green	

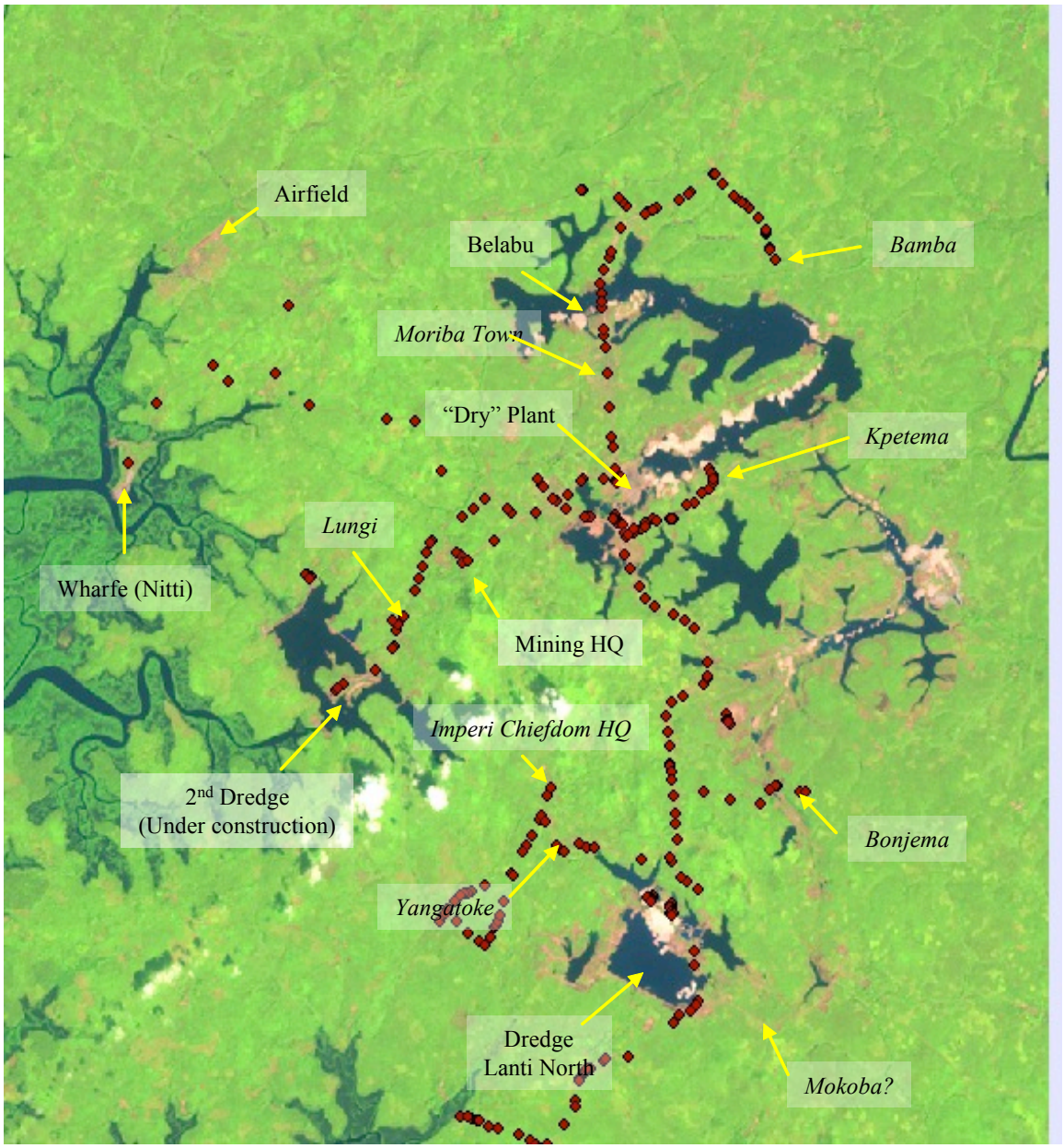

Figure 1. Map of the SRL mining concession (Note Richard can we get a better map I like the satailte image and when publishing in an online journal I think they will accept but perhaps line diagram would be best – what does everyone think?)

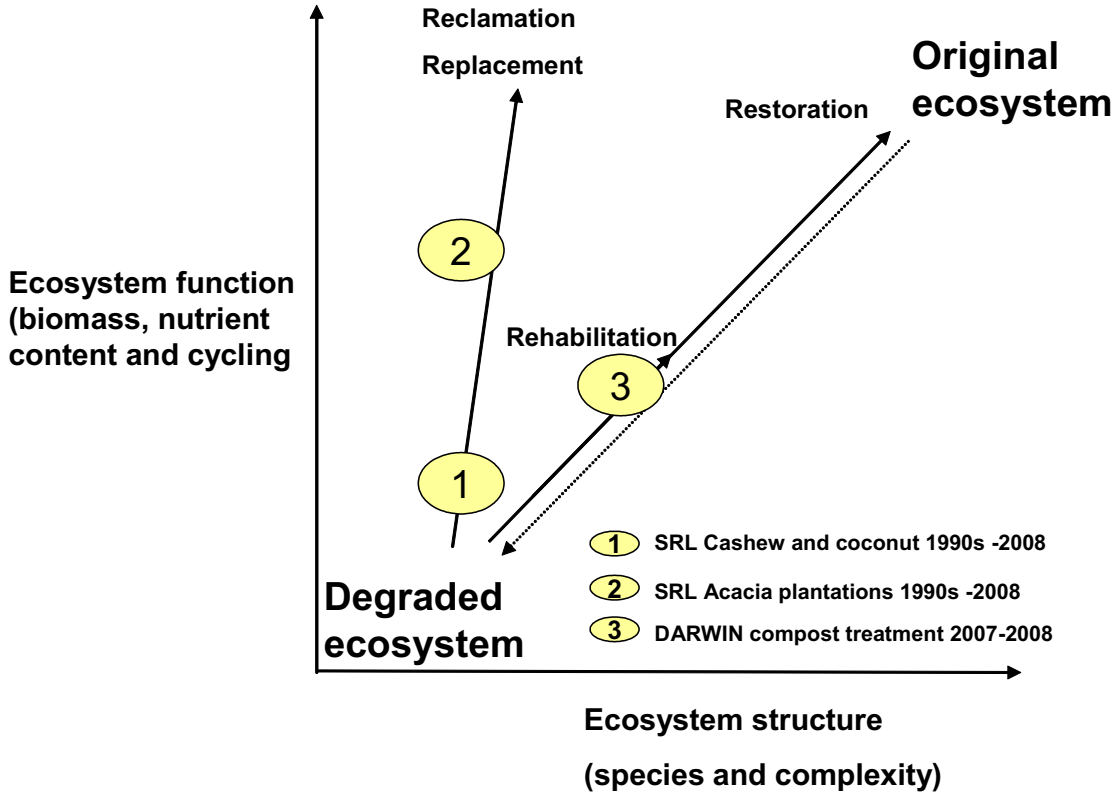

Figure 2 Schematic representation of improvement of degraded land showing relative position of revegetation efforts in the mining concession of SRL, Bonthe District, Sierra Leone (based on Bradshaw (2002))

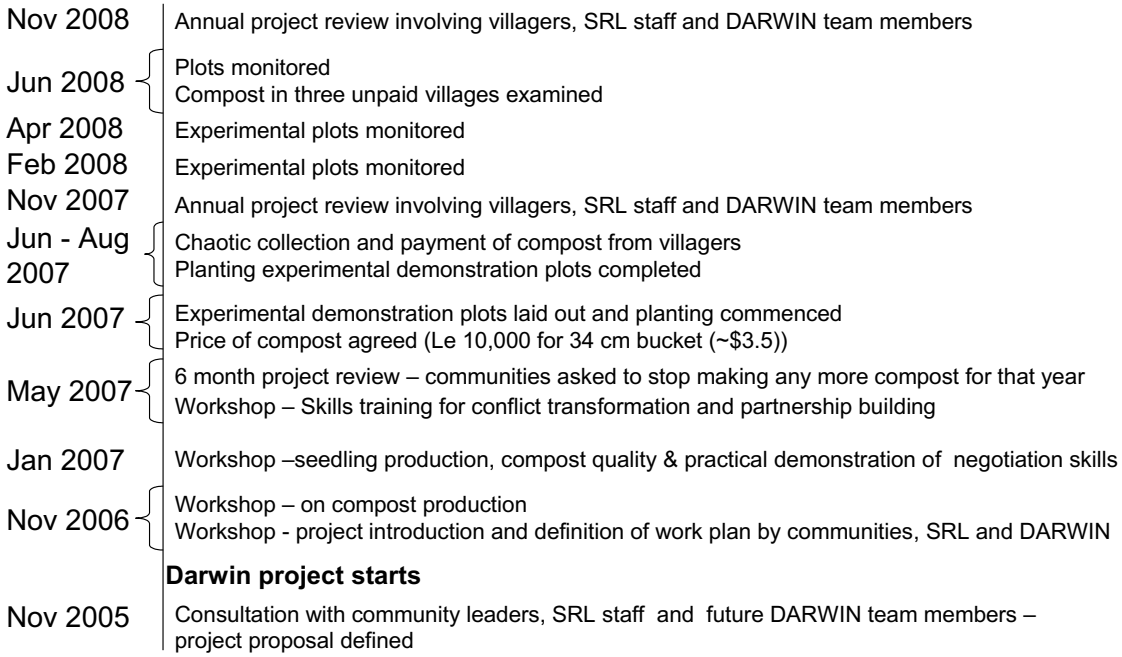

Figure 3 Time line of the first two years of the DARWIN project in SRL concession in south west Sierras Leone [Note the exact content of this diagram may change – comments welcome]

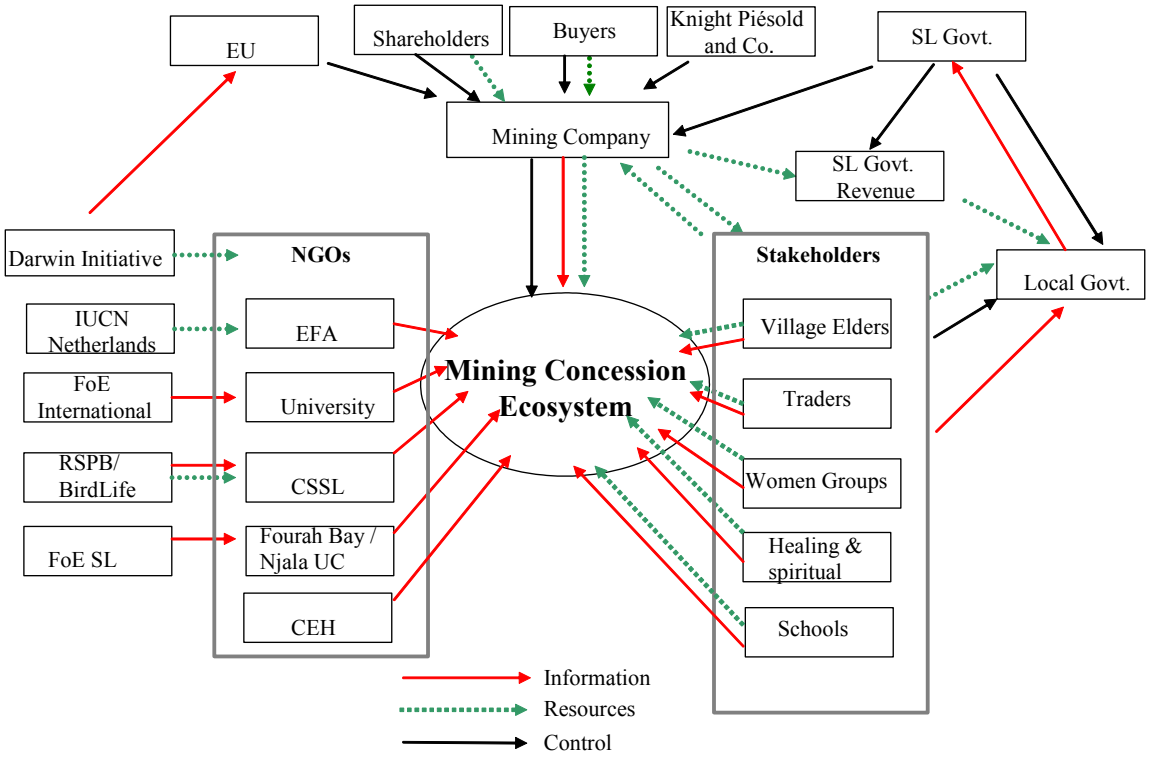

Fig 4 An actor network diagram showing lines of influence of the human actors on the SRL mining concession ecosystem, Sierra Leone. The ecosystem acts as a hub in this diagram and all actors feeding directly into the hub can be influenced by the information and resources flowing around the ecosystem.

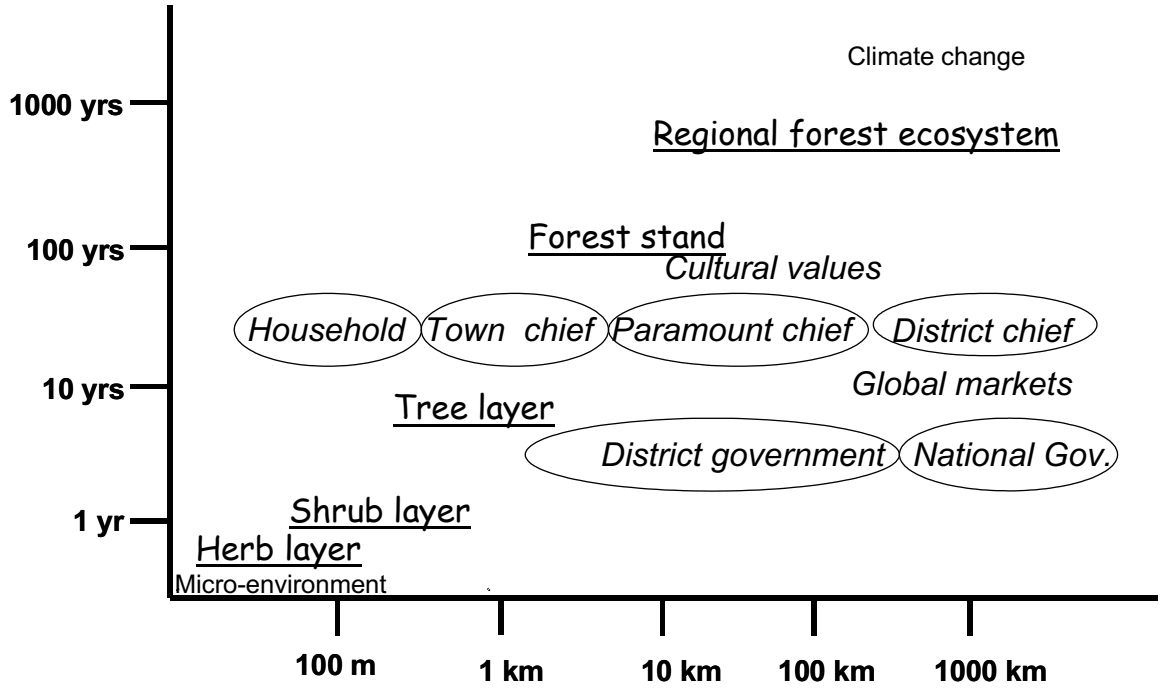

Figure 5 Time and space scale of vegetation, social and environmental hierarchies in south western coastal area of Sierra Leone

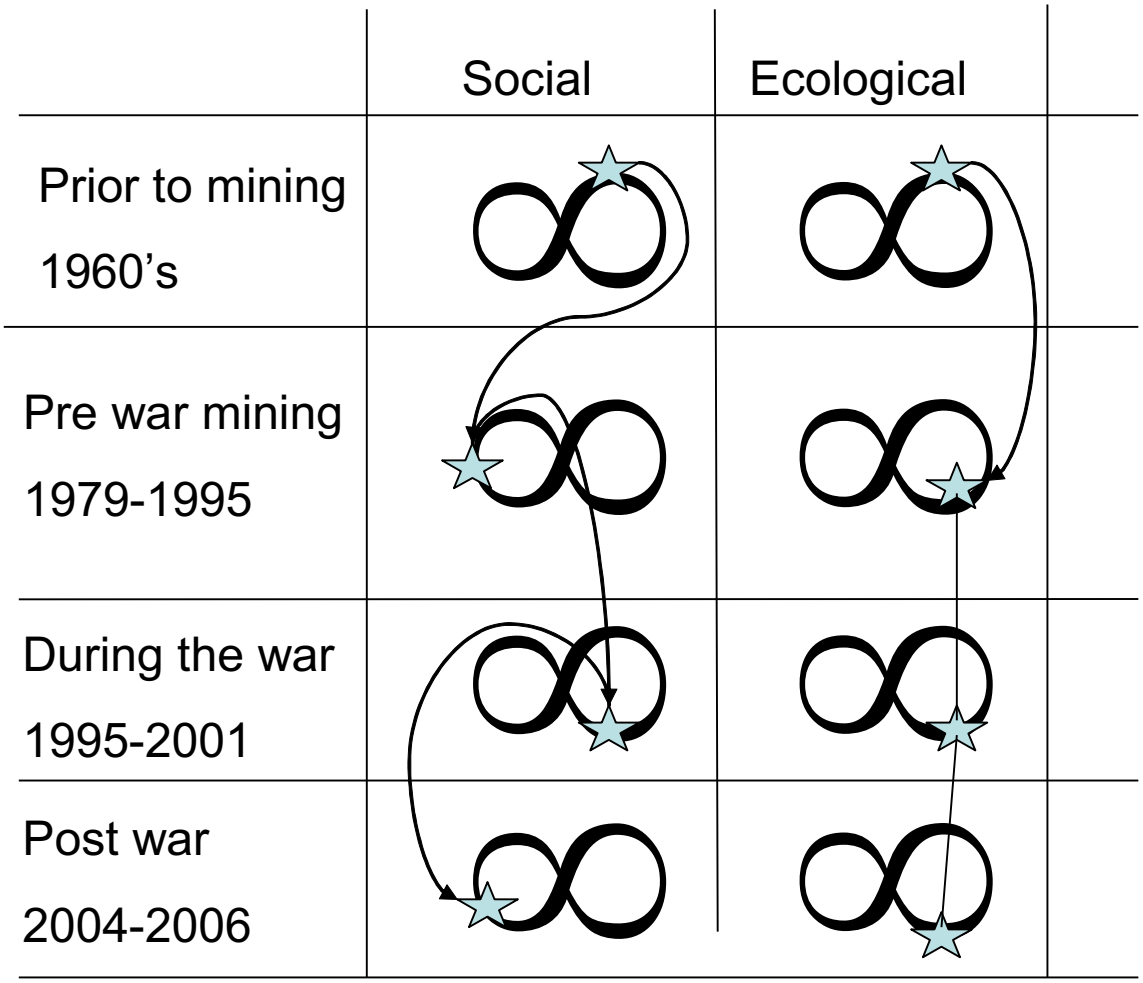

Fig. 6. Adaptive cycles showing the position of ecological processes and civil society in Sierra Lone in a mining concession area at four important time periods prior to the start of the DARWIN project.

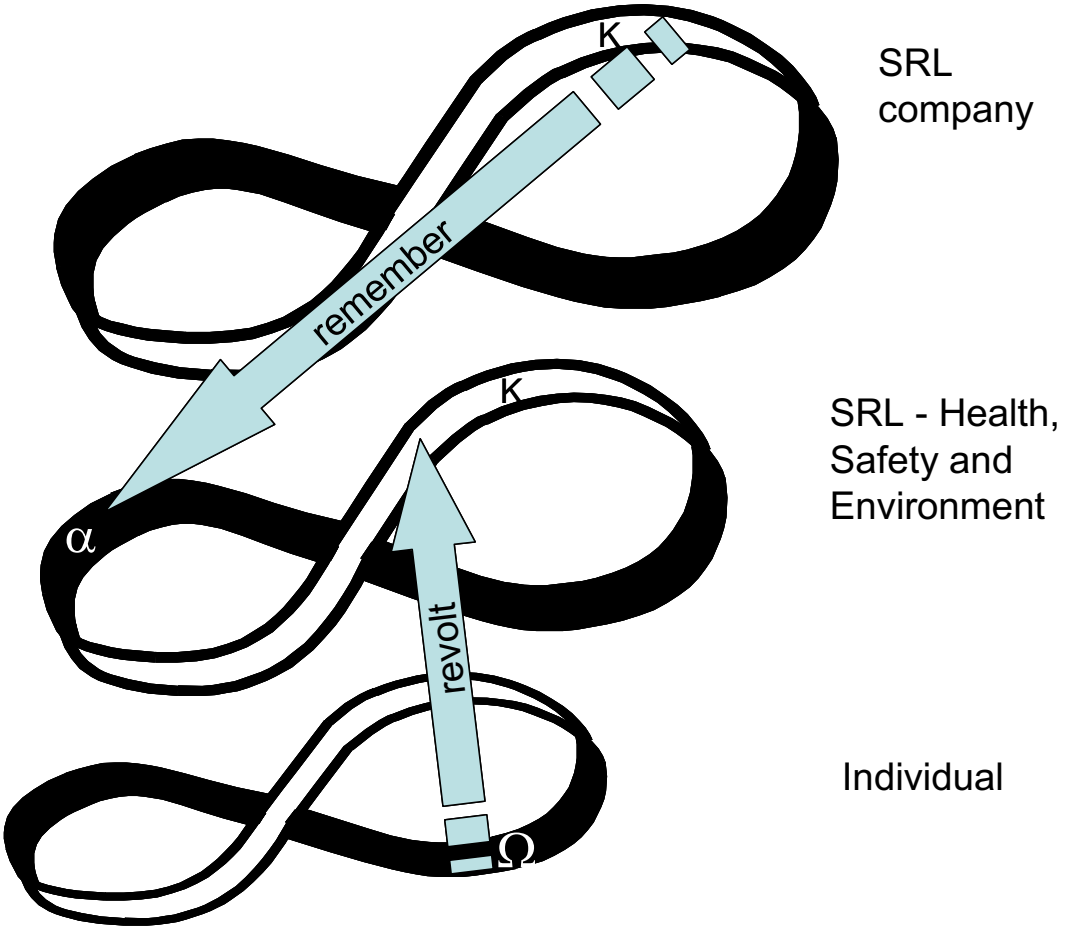

Figure 7 Relationship between the adaptive cycles of SRL company, the SRL department responsible for restoration (Healthy, Safety and Environment HSE) and the individuals: analysis reveals the larger slower cycle ‘remembered’ when all restoration was done ‘in house’ and because the intermediate cycle (HSE department) was re-entering the phase with new staff members it was venerable to infleunce of the high level; at the same time the indiviudals in the villages were not stable and saw an oppertunity to exploit the situation.

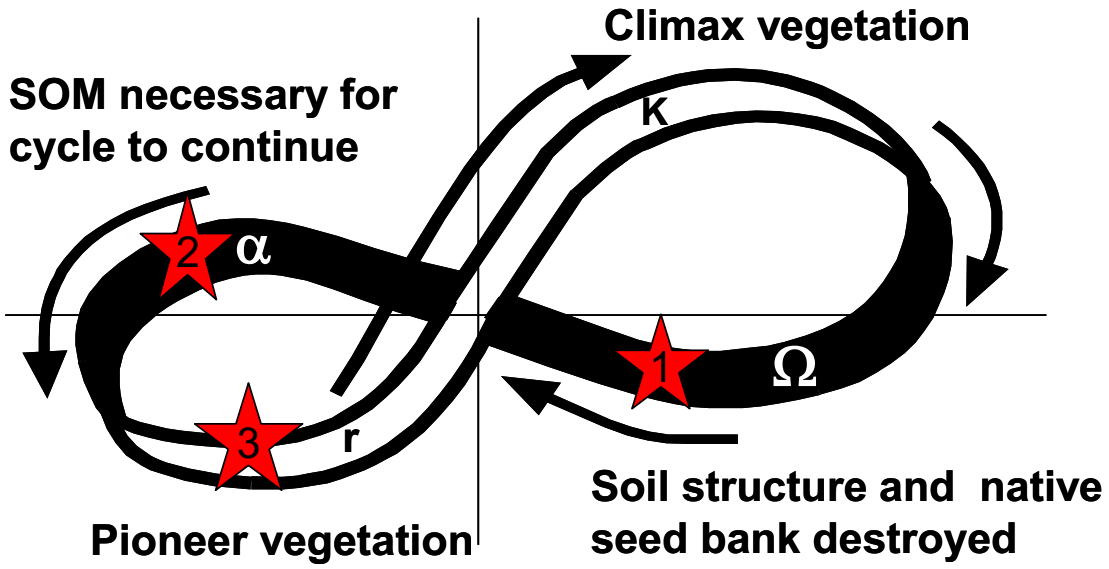

Figure 8 Adaptive cycle of the ecological recovery in the composted treated plots during the first two years of DARWIN project. The stars indicate significant points on the cycle: 1 = the position of the ecosystem effected by mining at the start of the project when it was in the collapse phase (Nov 2006); 2= the addition of village produced compost (June 2007) which had not been sufficiently heated to destroy the seed bank resulted in many species growing and a period of reorganisation of species assemblages; 3= indicates the position by Nov 2008 when annual crop plants were eliminated due to lack of seed but hardy perennials and wind blown annuals grew, the species assemblages resembled a natural pioneer community.