Applications of an unsupervised neural network to support sustainable development by modelling environmental, social and economic conditions

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In this paper, initially the circumstances that led to a need for ecologically sustainable development and the progress achieved in this regard are briefly looked at. Thereafter, applications of an unsupervised algorithmic neural network to aid sustainable development by modelling environmental, social and economic conditions of complex natural habitats using measurable variable data are reviewed.

Keywords: Sustainable development, Self-organising maps, ecological modelling.

1. Introduction

By the mid twentieth century, growing global environmental issues that resulted from until then practised 'sectoral' resource management approaches made humans to think beyond economic progress (Reid 2000). This led to the reinterpretation of the term 'sustainable development'; even made it a catchphrase (Department of the Environment and Heritage, Australia 2005). In the current context, sustainable development is defined as ecologically sustainable development involving societies at regional, national and even global scales (Harris 2002). As economic and social progress depends on fundamental ecosystem[1] services (such as oxygen production, carbon dioxide absorption by plants, and many more) and a healthy environment the latter are s*ine qua non* for achieving the former (Bierbaum 2001).

With the 1960s change of focus on sustainable development, many environmentally concerned national and international institutions made attempts to implement integrated resource management concepts within an ecosystem framework. However, several decades on, it is apparent that as far as global environmental sustainability is concerned much more remains to be achieved. Two of the many facts that support this statement are discussed herein: (i) Threats to human civilisation by the end of this century, not in millions of years time as earlier predicted, if the current anthropogenic climate change continued (Barrett and Salinger in Fairfax New Zealand Limited 2005). This warning comes from New Zealand (NZ) scientists researching on the past of Antarctic ice sheets. The research described the current path as directed towards doom which could turn many currently above see level land into uninhabitable, much sooner than earlier predicted. (ii) The failed United Nations (UN) efforts in addressing the concerns over anthropogenic environmental issues. The UN efforts produced great hopes and high expectations nonetheless they were never matched with real progress in the implementation of sustainable development, as a result environmental degradation continued unabated (United Nations 2002).

The main reason for the continued environmental deterioration has long been attributed to uninformed decisions made on natural resources use and management that failed to give due consideration to the wider implications on the ecosystems concerned. On the other hand, the widely available digital data on environmental, social and economic conditions of habitats could not be analysed within an ecosystem framework due to (i) the wide gaps in the data and (ii) lack of methods for modelling data on various ecosystem conditions integrated (Hammond, et al. 1995). The dilemma with conventional data analysis methods used for ecosystem modelling has been overcome with considerable success by employing novel approaches using Kohonen's (1982), self-organising map (SOM) techniques. A SOM is a feed forward unsupervised algorithmic artificial neutral network paradigm, developed from late twentieth century's neurophysiological understandings of the human brain's cortex cells. In section 2, events and details associated with sustainable development and in 3, successful SOM applications to integrated analysis of complex habitat data and possible ecosystem dynamics prediction models are discussed.

2. Sustainable development

Until the early 1960s, resource managers and decision-makers were concerned only about one issue; achieving their own objectives, such as increased food production or timber supply, all of which had an ultimate goal of gaining economic progress with no concern whatsoever on the damage caused to the environment (Reid 2000). In fact, it is argued in (Buckeridge 1999) that the said professionals still continue to do so, believing that natural resources are in a plethora. With this kind of attitude, concurrent narrowing down of scientific fields (Bowler 1992), decisions made on resource management without any concern on the 'big picture' issues on ecosystems as a whole, have caused massive environmental deterioration with immense damage to biodiversity (Clark et al. 2001).

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[1] An ecosystem is "A biological community *termed as a biological system herein* and the physical environment, *which in turn is termed as the physical/environmental system* associated with it…" Concise Science Dictionary (1991). Oxford Reference. (*Attention of italics is for specific clarification in this paper*).

The early 1960s initial recognition of human influence as the main cause for the staggering global environmental issues, brought about a raft of events, first and foremost, this triggered environmentalists to lobby state and international institutions, such as the UN, for more compelling measures to enforce ecologically sustainable development and to conserve natural habitats (Department of the Environment and Heritage, Australia 2005). Following a few UN initiatives, international forums and debates, such as *the Human Environment* 1972 and *Habitat* 1976, the need for a changed approach to development was approved in view of human well-being on Earth. The popular Bruntland Report *Our Common Future* 1987 played a major part in popularising the term 'sustainable development'. The UN's Rio de Janeiro Conference on *Environment and Development* 1992 (also known as *the Earth Summit*) produced Agenda 21, a major publication that sets out a blueprint for sustainable activity across all areas of human endeavour. Meanwhile, countries like New Zealand and Australia along with many other developed countries made attempts to achieve sustainable development through integrated management approaches, namely, 4Es (economics, ecology, ethics and engineering) (Buckeridge 1994), triple bottom line, and Pressure-state-response (PSR) models (Hammond, et al. 1995; Ministry for the Environment 2002). However, the UN's report on *The Road from Johannesburg, World Summit on Sustainable Development-What was achieved and the way forward* 2002 clearly shows that there is much more to achieve to avert the following impending threat to humanity.

NZ scientists researching on Antarctic ice sheets warned of threats to human civilisation by the end of this century much sooner than earlier predictions. Indications are such that with the current levels of greenhouse gas emission, global temperatures would continue to increase further by three to four degrees in the next few decades (Barrett and Salinger in Fairfax New Zealand Limited 2005). Based on the past of Antarctic climate, the research showed that due to this anticipated temperature increase sea levels would rise making many now liveable areas into uninhabitable. The study identified Western Europe, the American state of Florida and low-lying countries like Bangladesh as the areas most likely to become uninhabitable. The report further stated that smaller climatic changes had destroyed past civilizations and humanity could not run the risk of rising carbon dioxide levels as last time when carbon dioxide levels were this high humans had not evolved. Antarctic ice research revealed that carbon dioxide ranged between 180 and 280 parts per million (ppm) during natural cycles caused by changes in the Earth's orbit over the past 400,000 years, but **had now reached 374 ppm.** In an earlier report, one of the above authors, Barrett mentioned of the refusal by the United States and Australia to adopt the Kyoto protocol measures, when "… **even the Kyoto Protocol on global warming would not be enough to avert a climate disaster**." Hence, nations need to do more than Kyoto protocol to avert the said disasters.

With that brief history on sustainable development, in the next section, examples of SOM applications that could aid resource managers in this regard are discussed

3. SOM applications

Successful SOM applications to support sustainable development by modelling multi dimensional ecological data integrated with socio-economic conditions of complex natural habitats are discussed in this section.

3.1 SOMs in species distribution modelling

SOM applications to analysing biological population dynamics of forest (Giraudel and Lek 2001) and freshwater (Ce´re´ghino et al. 2001) using species data were found to be successful, the former described the algorithm as a useful tool for exploratory data analysis in ecology that could be used in complementary to the existing classical techniques. In the latter, SOMs were successfully applied to clustering the community patterning in the regional distribution of 283 lotic macroinvertebrate species within data that consisted of four insect orders (Ephemeroptera, Plecoptera, Trichoptera, Coleoptera = EPTC) from the Adour-Garonne drainage basin of Southwest France, an area of 116,000 km^2. The aim of the research was to provide a stream classification based on characteristic species assemblages using the occurrence of these species at 252 sampling sites. SOMs were found to be useful in projecting this high dimensional data set onto two-dimensional (U-matrix) displays for easy visualisation while preserving the topology of the input vectors. The SOM displays identified the characteristic EPTC distribution underlying the spatial distribution within the raw data, which had no information included in this regard. In this application, SOMs provided a means to analyse the data with four orders (EPTC), covering a relatively larger region that consisted of high mountain to plain and coastal areas whereas, previous studies had been confined to a single taxonomic group (one insect order) and within a single valley or mountain. The study also stated that the SOM classification of EPTC distribution could be extended to detect environmental changes in the region.

3.2 SOMs in biotic index pollution analysis

In (Murray-Bligh 1998) SOMs are considered to have shown "…considerable potential for diagnosing different types of pollution…." In this system, SOM methods are applied to calculate the biotic indices based on the distribution and abundance of BMWP[2] taxa for establishing a systems water quality index.

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[2] The BMWP scores are devised for the taxonomic families occurring in British rivers, depending upon their sensitivity to organic pollution, those very sensitive to organic pollution with 10, down to families more tolerant of pollution with 3 or less.

3.3 SOMs in ecological dynamics modelling

In (Shanmuganathan et al. 2001, 2002, 2003 and 2004) how SOM techniques could be best applied to visualise environmental impact results and their causal processes is illustrated. In these papers, environmental, social and economic conditions of highly complex and dynamic habitats represented by measurable variable data were analysed integrated using SOM techniques.

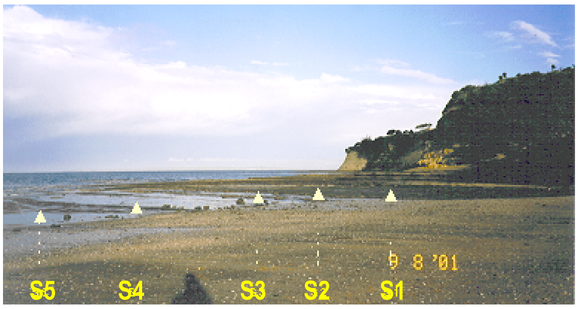


Figure 1 : Photograph showing the slate tile positions at the Long Bay-Okura Marine Reserve, north of Auckland, New Zealand

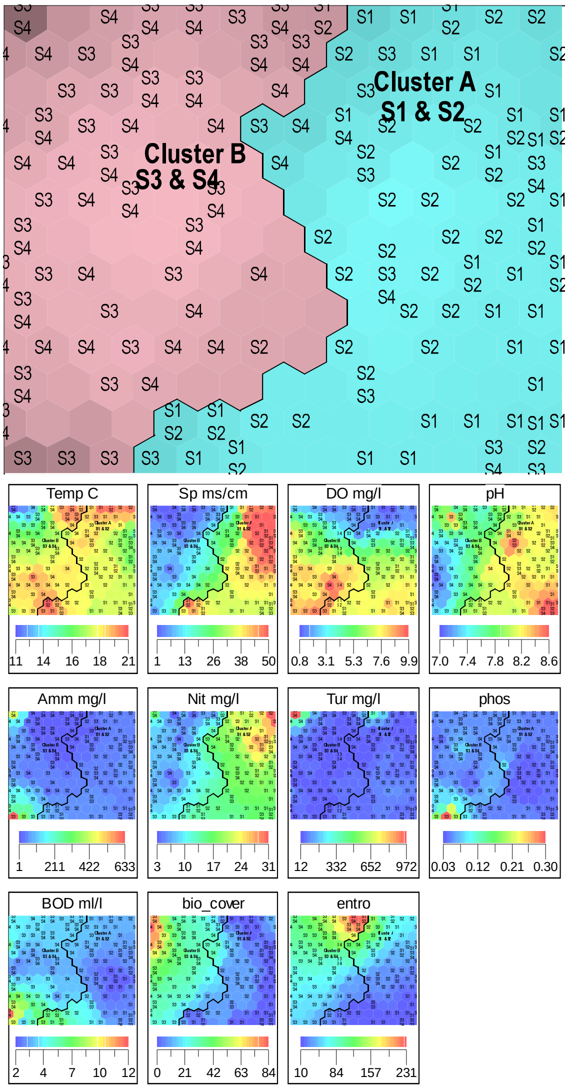


Figure 2: SOM and componet planes of the Long Bay-Okura Marine Reserve's physical and biological system data

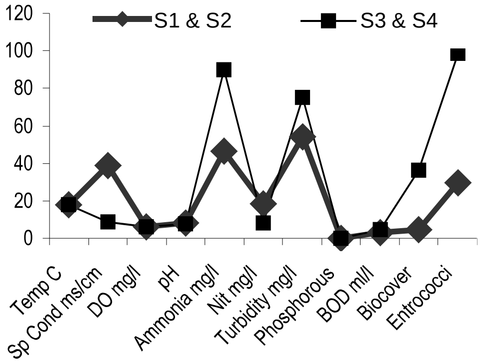


Figure 3: Graph showing the SOM clusters.

Cluster	A (S1 & S2)	B (S3 & S4)
Component	Mean	Mean
Temp C	18.04	17.66
S Conductivity ms/cm	**38.72**	**8.65**
DO mg/l	6.16	5.89
pH	8.31	7.57
Ammonia mg/l	**46.6**	**90**
Nit mg/l	**18.47**	**8.04**
Turbidity mg/l	**54**	**75**
Phosphorous	0.0413	0.0671
BOD ml/l	**2.89**	**4.62**
Biocover	**4.73**	**36.22**
Entrococci	**29.6**	**98.5**

Figure 4: Details of SOM clusters (figure 2).

The SOM displays improved analysis and visualisation of dissimilar data sets enhancing the detection of distinctive patterns within them by clustering similar data points together. For example, in (Shanmuganathan et al. 2001), environmental conditions and their effects on biological systems observed at the Long Bay's Okura Marine Reserve in northern New Zealand were modelled using dissimilar data collected by different groups of researchers. In this analysis, micro climatic variations as well as sessile invertebrate population dynamics within this reserves intertidal zone were visualised on two-dimensional (U-matrix) SOM displays. The reserves intertidal zone consists of lower supra, upper, mid, lower and upper sub littoral, represented by S1-S5 along a chosen transect (figure 1).

The SOMs clearly showed the relationships between the environmental system attributes and the reserves intertidal biological systems dynamics under different scenarios, such as the eutrophic conditions, observed in the reserve. In the SOM analyses, the growth of sciaphilic organisms (those organisms that encrust the rock surfaces), in percentages of bio cover observed on already fixed 1 square foot slate tiles in (S1-S4), represented the reserves intertidal population dynamics (see appendix 1 for species details and their characteristic zoning). Temperature, pH, ammonia, nitrate, biological oxygen in demand (BOD), dissolved oxygen (DO), and *Entrococci* data of water samplings from the same locations, represented the environmental system changes within the zone (see figure 4 for full list of attributes and details). In the SOM (figure 2) data from the first four subdivisions of this zone, labelled as S1-S4, can be seen clustered into two broad clusters (A & B) except for a few cross-over along the main line. This shows SOM ability to distinguish even the subtle spatial and temporal variations within the physical and biological variables analysed (figures 3 and 4). It enabled analysts to study the environmental effects on this reserves intertidal population dynamics. In the next section, SOM applications to analyse ecological dynamics of this zone is illustrated.

3.4 SOM prediction models

In this section, how SOMs could be applied to model ecological dynamics is illustrated. The first example is based on the above Long Bay Marine Reserve data. In this study, SOM trajectories are applied to the reserves S1, that is, lower supra division data on a six cluster SOM (figure 5 b) of S1-S4 data. By tracking the SI changes over time, its entry towards undesirable areas, such as high *Entercocci*, could be detected in advance. The approach is applied with considerable success to predicting complex industrial system dynamics to avoid breakdowns in manufacturing, electricity and other plants. It is regarded as a useful tool in the monitoring and control of such complex systems using measurable variable data (Simula et al. 1998 & 1999).

Cluster	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
Component	S3&S4	S1&S2	S1&S2	S3&S4	S3&S4	S3&S4
Temp C	17.1	17.99	18.2	*18.69*	*19.61*	11.3
Sp ms/cm	8.73	38.12	40.55	*11.22*	*5.92*	1.55
DO mg/l	6.31	7.28	2.7	*8.17*	*1.5*	2.45
pH	7.62	8.34	8.23	*7.25*	*7.77*	7.79
Ammonia mg/l	50	50.6	34.1	*232.3*	*4.6*	428.9
Nit mg/l	7.67	16.96	23.17	*8.14*	*8.15*	15.93
Tur mg/l	57	55	53	*44*	*49*	972
phosphate	0.05	0.04	0.047	*0.12*	*0.052*	0.049
BOD ml/l	3.77	2.92	2.8	***8.08***	*3.5*	4.16
biocover	40.5	4.01	6.97	*28.65*	*22.13*	75.24
Enterococci	87.1	17.2	67.9	*56.7*	***203.8***	105.5

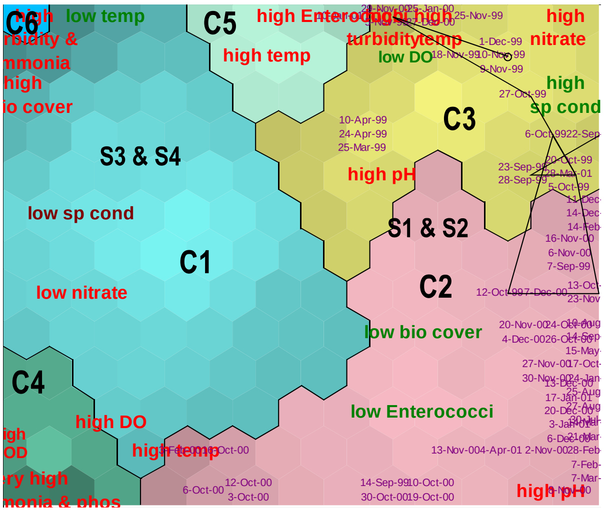


Figure 5: a-SOM cluster details b-Trajectory of S1 data on S1 - S4 SOM during 23 sep to 9 Nov 1999.

Figure 5 b, shows the trajectory during 23-Sep-99, 28-Sep-99, 5-Oct-99, 6-Oct-99, 12-Oct-99, 3-Oct-99, 20-Oct-99, 27-Oct-99, 5-Nov-99 and 9-Nov-99 time period in this subdivision (S1). It can be observed that by 27 October 1999 the water quality readings are heading toward high *Entrcocci* area.

Modelling Patterns in Environmental Data (MOPED) uses SOM techniques for mapping patterns in freshwater system data, such as fish species distribution and elevation of freshwater systems, and to predict the biological assemblages that should be present in certain streams (Jowett 2001). Finally, a SOM application to modelling population dynamics is illustrated.

In (Shanmuganathan. et al 2002) subtidal population dynamics along the northeast coast of Auckland is modelled using SOM techniques. For this study SOMs were created with data on 42 subtidal species collected from six beaches, (from Campbells Bay to Waiwera, five sites from each beach, see figure 6) from 1999 to 2001 (for details on species see appendix 2). In this study, the relationship between the observed sedimentation rates and its effects on subtidal population dynamics along this coast was analysed. The analysis was based on a similar approach used to study the gold price variations that were found to be dependent upon a few other identified macro economic variables (Eudaptics software gmbh 1998). The basic concept behind the approach is that with SOM techniques, the variability of a dependent variable could be modelled using its determinant variables.

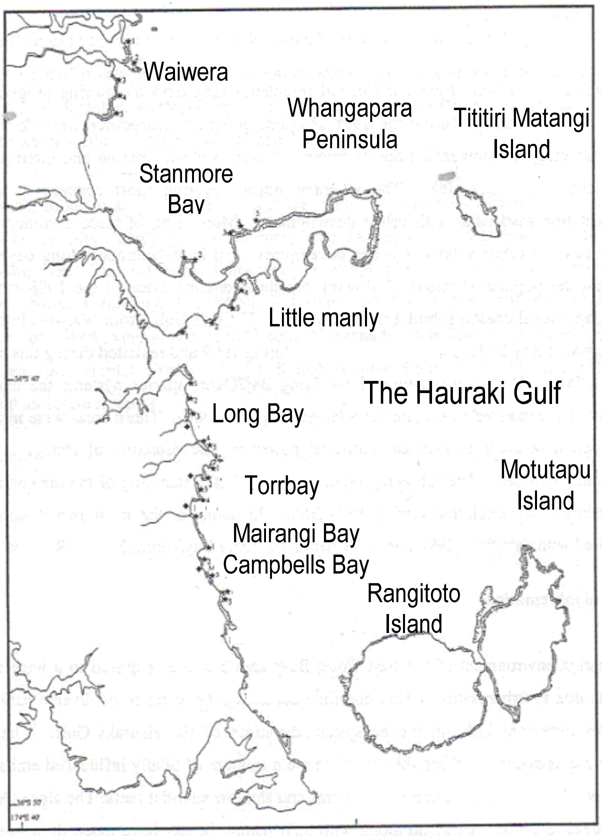


Figure 6: Map showing the six beaches northeast of Auckland, New Zealand.

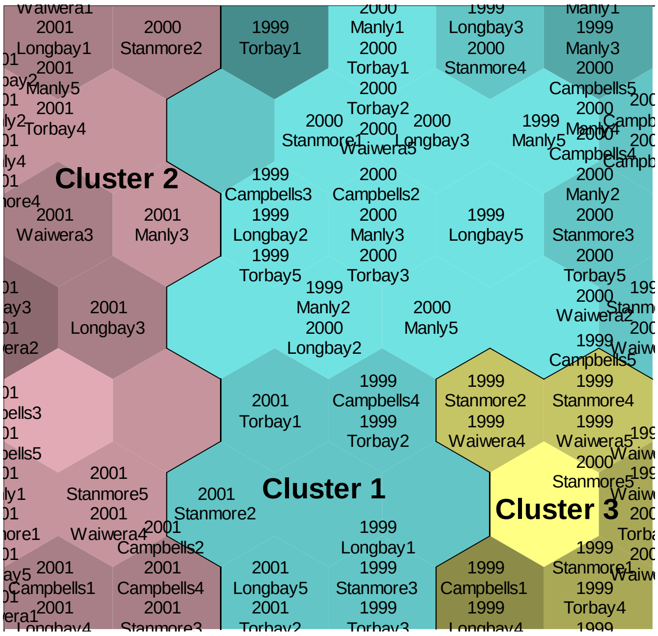


Figure 7: SOM of subtidal species and sedimentation data from six beaches northeast coast of Auckland, New Zealand

Firstly, clustering patterns within a SOM (Figure 7) created with 42 species average count data and sedimentation rates, for the three-year period along the coast were analysed. It is interesting to note that Waiwera data points clearly show the annual variations within this population dynamics, while the other sites seem to vary, which indicate the effects of sedimentation in those areas (figures 7 & 9). In this analysis, sedimentation, calculated in percentages of <63 microns, was considered as an indicator of urbanisation. With conventional methodologies based on Before-After-Control-Impact design (Walker et al. 2000) identified the annual variations and a few potential indicator species within this data. However, the conventional analysis results were complicated with many graphs whereas, the SOMs give a better tool for visualising multi dimensional data sets with non-linear and unpredictable correlations.

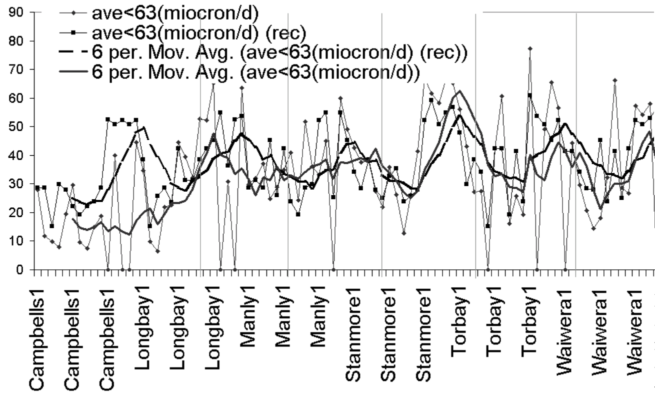
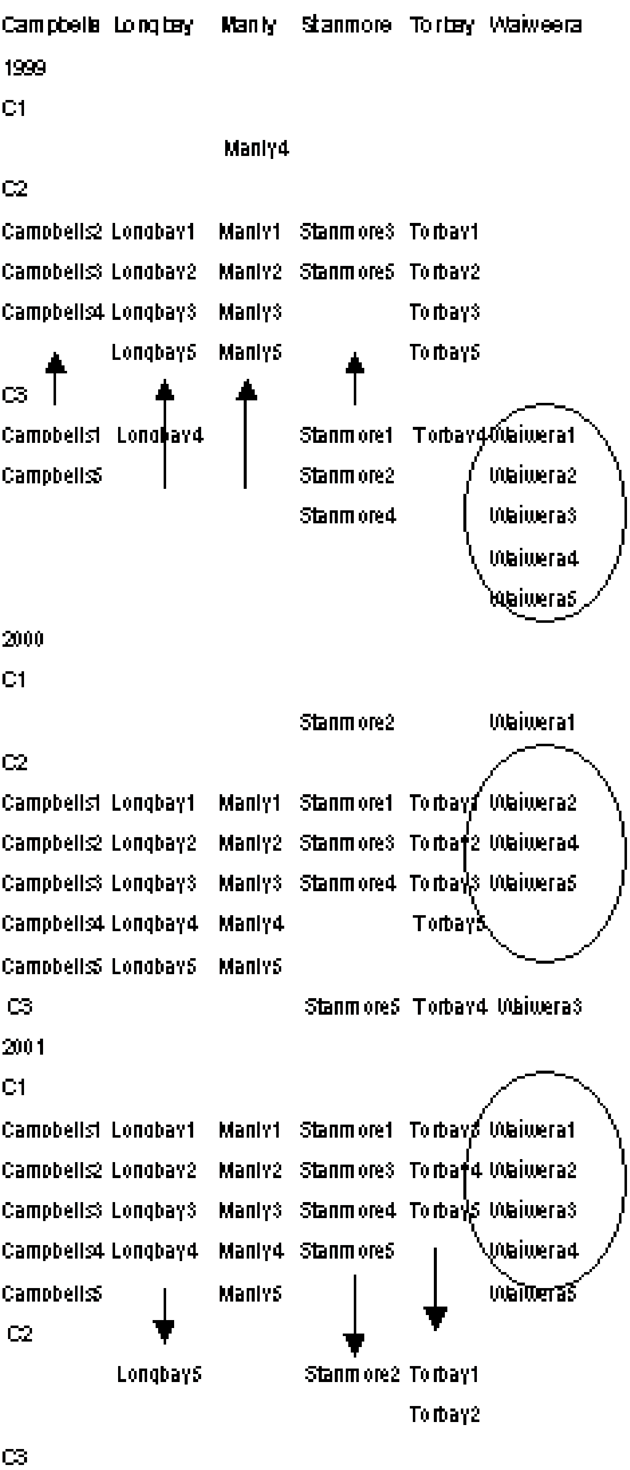


Figure 8: Graph showing the real sedimentation (percentages of <63 microns) and SOM prediction values. 1999-2001 values are shown left to right.



Campbells	Longbay	Manly	Stanmore	Torbay	Waiweera
1999					
C1					
		Manly4			
C2					
Campbells2	Longbay1	Manly1	Stanmore3	Torbay1	
Campbells3	Longbay2	Manly2	Stanmore5	Torbay2	
Campbells4	Longbay3	Manly3		Torbay3	
	Longbay5	Manly5		Torbay5	
C3					
Campbells1	Longbay4		Stanmore1	Torbay4	Waiwera1
Campbells5			Stanmore2		Waiwera2
			Stanmore4		Waiwera3
					Waiwera4
					Waiwera5
2000					
C1					
			Stanmore2		Waiwera1
C2					
Campbells1	Longbay1	Manly1	Stanmore1	Torbay1	Waiwera2
Campbells2	Longbay2	Manly2	Stanmore3	Torbay2	Waiwera4
Campbells3	Longbay3	Manly3	Stanmore4	Torbay3	Waiwera5
Campbells4	Longbay4	Manly4		Torbay5	
Campbells5	Longbay5	Manly5			
C3			Stanmore5	Torbay4	Waiwera3
2001					
C1					
Campbells1	Longbay1	Manly1	Stanmore1	Torbay3	Waiwera1
Campbells2	Longbay2	Manly2	Stanmore3	Torbay4	Waiwera2
Campbells3	Longbay3	Manly3	Stanmore4	Torbay5	Waiwera3
Campbells4	Longbay4	Manly4	Stanmore5		Waiwera4
Campbells5		Manly5			Waiwera5
C2					
	Longbay5		Stanmore2	Torbay1	
				Torbay2	
C3					

Figure 9: Table showing SOM (figure 7) cluster grouping details in which Waiwera data show the annual variation along this coastal area.

In a graph of real sedimentation percentages of <63 microns and the SOM prediction values derived from population dynamics along the coast (figure 8), the latter values are almost same as that of the real. Also, the prediction trend is seen to follow that of the real except for Campbells Bay 2001, Long bay 1999 and Manly 1999, where the real data set has got missing values.

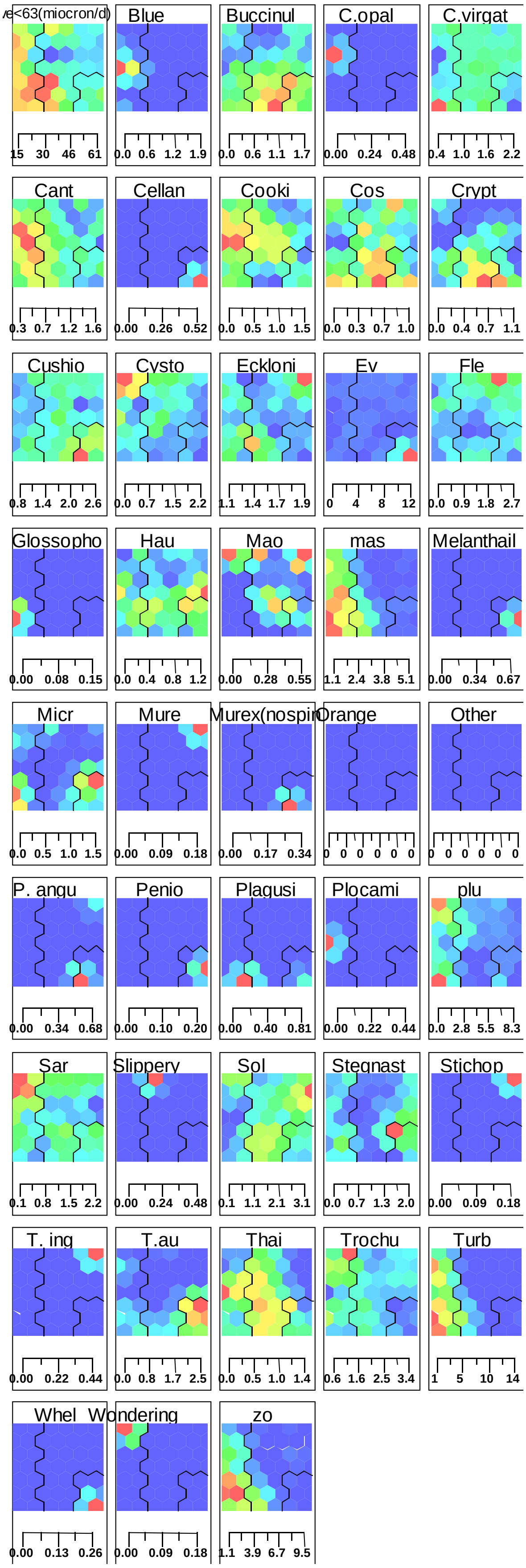


Figure 10: SOM components showing the patterns in subtidal species and sedimentation data from the six beaches analysed.

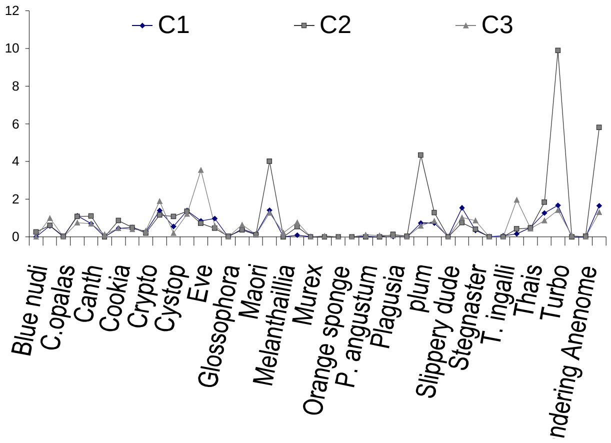


Figure 11: SOM of subtidal species and sedimentation data from six beaches northeast coast of Auckland, New Zealand.

Of the specie average count data analysed using the SOM clustering patterns (figures 10 and 11), a few show a negative correlation to the observed sedimentation along the coast: They are: Echinoderms: *Patiriella regularis*, *Evechinus chloroticus*, *Stegnaster inflatus*, and a sponges species *Tethya aurantium*. Macroalgae *Carpophyllum flexuosum* show a negative correlation to an extent. A few more species show positive response during the year 2001, they are: macro algae *Carpophyllum maschalocarpum*, *Carpophyllum plumosum*, *Sargassum sinclairii*, *Zonaria turneriana* along with herbivorous gastropods *Turbo smaragdus*, *Trochus viridus*, Predatory whelk *Thais orbita*, *Cookia sulcata* and *Cantharidus purpureus*.

For more details on these SOM applications please see the original publications.

4. Conclusion

Despite the redefining of sustainable development as ecologically sustainable development involving societies at wider scales and the desperate measures taken by the UN, progress made so far in achieving global environmental sustainability is too little too late in averting the imminent threats to human civilisation. The key factor for this has long been attributed to human interference on our global ecosystem. Humans have caused major shifts in the balance of environmental cycles (Clark et al. 2001), for which uninformed choices made by resource managers and decision makers are blamed (Reid 2000), who in turn endure technical hitches in utilising disparate ecosystem data and lack methods for performing trade-off analysis on the use and preservation of natural resources (Hammond, et al. 1995). The SOM applications to ecosystem modelling using ecological, social and economic conditions illustrated in this paper showed how SOM techniques based on an unsupervised network could be used to support sustainable development of complex habitats.

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SOMs used in the paper were created using Viscovery, a commercial data mining software package developed by (Eudaptics software gmbh 1998).

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Appendix 1

Long Bay-Okura Marine Reserves subdivisions within its intertidal zone and their key species

Zone	Key species observed on slate tiles
Lower supralittoral-S1	*Chamaesipho columna*
Upper littoral-S2	*Chamaesipho columna*
	Epopella plicata
Mid littoral-S3	*Austrominius modestus*
	Crassostrea gigas
	Pomatoceras caeruleus
	Cyanobacteria
Lower littoral-S4	*Austrominius modestus*
	Pomatoceras caeruleus
	Xenostrobus pulex
Upper sub littoral-S5	*Austrominius modestus*
	Balanus trigonus
	Cyanobacteria
	Corallina officinalis

Buckeridge, J. S. (1999). Stochastic Urban Accretion and Marine Reserves: Complementary or Conflicting options? 19th Annual Meeting of the International Association for Impact Assessment for a New Century, Glasgow, Scotland

Appendix 2

2000 Subtidal survey species list (Pages 71-72)

Species	Common name	Abundance
Macroalgae		
Carpophyllumflexuosum	Flexible flapjack	Abundant
Carpophyllum maschalocarpum	Common flapjack	Abundant
Zonaria turneriana	Fan weed	Abundant
Ecklonia radiata	Paddle weed	Common
Carpophyllum plumosum		*Common*
Cystophora retroflexa	Slender zigzag	Common
Sargassum sinclairii		*Common*
Xiphophora chondrophylla		*V. shallow*
Codium fragile.		Rare
Herbivorous gastropods		
Turbo smaragdus	Cats eye	Abundant
Maoricolpus roseus	Turret shell	Rare
Trochus viridus	Green topshell	Rare
Cantharidus purpureus	Red topshell	Rare
Cookia sulcata	Cook's turban	Rare
Micrelenchus	Small opal topshell	V. rare
Predatory whelks		
Cominella virgata	Spotted whelk	Common
Cominella adspersa	Speckled whelk	V. rare
Cominella maculosa	Spotted whelk	V. rare
Buccinulum lineum	Lined whelk	Common
Haustrum haustorium	Dark rockshell	Rare
Thais orbita	White rockshell	Rare
Charonia lampas rubicunda	Large trumpet	V. rare

Echinoderms

Evechinus chloroticus	Kina	Common
Holopneustes	Pink urchin	Very rare
Patiriella regularis	Cushion star	Common
Stegnaster inflatus	Crazy star	Rare
Coscinasterias calamaria	*11* arm starfish	Rare
Stichopus nwilis	Sea cucumber	Rare

Sponges

Tethya aurantium	Orange golf ball sponge	Common
Tethya ingalli	Pink golf ball sponge	Rare
Polymastia croceus		*V.* rare
P. jusca		*V.* rare
Aaptos aaptos		Rare
Cliona celdta	Boring sponge	Common

Other species

Cryptoconchus porosus	Chiton	Rare
Asterocarpa coerulea	Blue ascidian	Rare
Cnemidocarpa nisiotis	Mottled ascidian	Rare
Cnemidocarpa bicor-nuata	Orange ascidian	Common
Plagusia chabrus	Red rock crab	Common
Pagurus novaezelandiae	Hermit crabs	Common

Encrusting algae

Coralline Paint	Crustose coralline algae	Abundant
Corallina officinalis	Coralline turf	Common
Unidentified green turfing algae		Rare
Unidentified red turfing algae		V.rare

Walker J, R Babcock and B Creese (2000). The Long Bay Monitoring Program Sampling Report - July 1999 / June 2000