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A Computerized Method for Identifying Dispersal Corridors, Using West-Coast Renosterveld as an Example

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Abstract: In this letter we look at a computerized method of identifying pathways based upon a cost-analysis method. Using this method complicated or large-area land-cover patterns can be assessed. We use the example of West-Coast Renosterveld, a vegetation type that has been highly transformed by agriculture.

Keywords: Dispersal corridors, fragmented habitat, west-coast renosterveld, computer method.

INTRODUCTION

Over the past 6 decades, the human population has increased from about 2521 billion in 1950 to about 6707 billion in 2008 [1]. The demand for food and living space has likewise increased. Urbanisation has similarly resulted in cities and suburbs expanding at, sometimes, phenomenal rates. Natural and pseudo-natural areas are rapidly disappearing as formal, and in developing countries informal, dwellings are erected. Those natural areas remaining are often small and isolated from each other by a landscape that is hostile to all but a few species that have benefited by urbanisation or agriculture.

Added to this is the realisation that, as the climate of the earth changes, species which, under past climate change regimes were able to move to more suitable niches, are now imprisoned. Of course, changes in the macro-climate have always led to extinctions, and to the evolution, or adaptation, of other species to exploit the vacated niche [*e.g.* 2]. However, with the current excessive level of fragmentation, abnormally high levels of extinction may be expected with future changes in the climate, due to the inability of those species with insufficient mobility to "migrate" across transformed landscapes to other suitable areas. Even without climate change, genetic isolation, competition from aliens and the input of toxins and fertilisers into the remaining fragments are likely to send many species into oblivion.

There has been a great deal of discussion as to the usefulness or otherwise of dispersal corridors, the cost of their upkeep, the high perimeter to area ratios etc. [*e.g*. 3], and it is not our intention to enlarge on this. Notably lacking are methods for identifying potential dispersal corridors across the landscape. That this is difficult to do is not disputed, as every species perceives the landscape differently, and hence there is no such thing as a "universal corridor". However, this should not prevent us from trying to identify least-distance and "most environmentally friendly" networks. Over small areas with a few (large) natural fragments, this can be done subjectively, by human observation. Where the area is extensive and the fragments are small, numerous and widely scattered, the exercise becomes more difficult. In addition to the difficulty of identifying general patterns by "eyeballing" a map, as the area being examined gets larger, the smaller fragments become lost in the background and are thus excluded from the analysis.

In this paper we examine the use of a "cost-analysis" system, as used by civil engineers, to identify potential dispersal routes, using West-Coast Renosterveld (WCR) plant species, and their pollinators as our example. WCR has recently been divided into a number of sub-units [4], but for conservation planning purposes it is currently considered a single entity [5].

WCR is one of the vegetation types making up the Fynbos Biome, or Cape Floral Kingdom, one of the richest in terms of species diversity in the world [6]. Much of this Biome is situated upon leached, sandy soils [7], that have little conventional agricultural value. Coastal Renosterveld (of which the West-Coast type is one) occurs where the soils have a substantial clay or loam content with nutrient levels that are suitable (with the addition of fertilizers) for growing wheat and vines [8]. This has led to WCR (Fig. **1**) becoming (arguably) the most transformed landscape within South Africa [9-11]. There have been a number of vegetation mapping exercises in this area over the past sixty years, each defining different original extents for WCR. This makes determining the amount remaining difficult to estimate, but it seems certain that less than 10% remains, the two latest estimates being 5% [5] and 9.4% [12].

The remaining fragments are mostly small (average = 39.6ha; median = 8.6ha; n = 1889 of greater than 3ha), and are scattered across 7974km^2 [13] of the landscape, mainly on hillsides and on rocky soils. The average distance separating the larger, ecologically viable fragments (>25 hectares) is 5.2 ± 4.7 km (median = 4.0 km; range = 1.2 to 51.3 km; n = 202). Our estimate of 25 ha as a minimum

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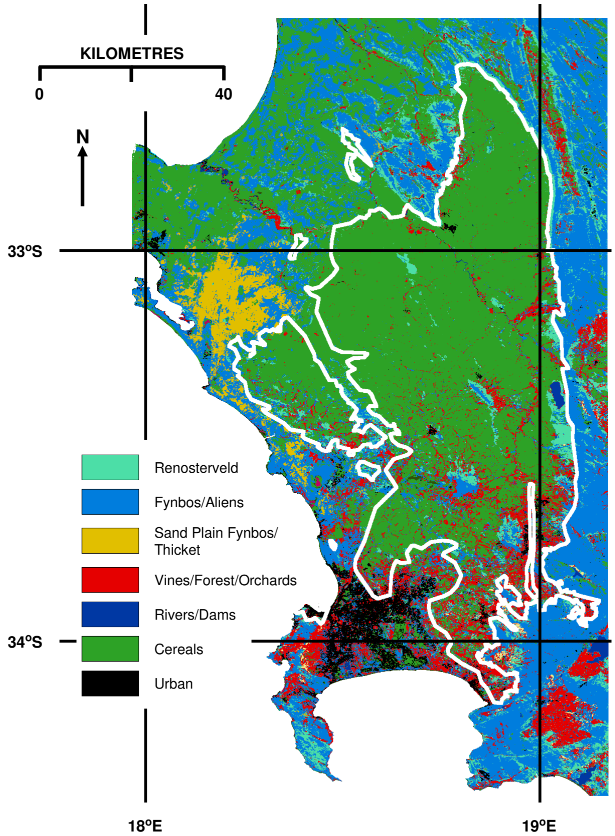

Fig. (1). Generalized land-cover map of the western lowlands of the Western Cape Province. White lines show the areas believed to have been the original extent of West-Coast Renosterveld.

fragment size for maintaining the viability of Renosterveld plant populations is based upon the work of [14] who examined the reproductive success of seven perennial plant species in fragments of different size. This is unfortunately the only study of this type available for Coastal Renosterveld. The Botanical Society of South Africa [5] produced a conservation plan for WCR and Overberg Renosterveld (which lies to the east of the Hottentots Holland mountains), which is being implemented by Cape Nature, the provincial nature conservation body. Little attention was paid to dispersal corridors in the plan. Those that were identified were confined to the linking of dissimilar vegetation types and to altitudinal corridors, neither of which have relevance for coastal Renosterveld endemic plants, due to their edaphic specialization.

The cost analysis system described here, assigns to each land-cover type a "cost" involved in crossing that land-cover type. For civil engineering purposes, this is relatively easy, as labour and equipment costs per unit distance are known in advance, and assessments of alternative routes can quickly be determined. There will still be imponderables involved, such as aesthetics, conservation concerns, and abnormal weather conditions, but most of these can be incorporated into the estimates of the contractor. Estimating the cost of dispersal of living organisms is much more difficult, as little or nothing is known about the biology of most of the species involved. However, compatibility ratings can be assigned to the various land-cover types, based upon their level of transformation and their frequency of disturbance. This is what we have done in this exercise.

Fig. (**2**) shows places mentioned in the text.

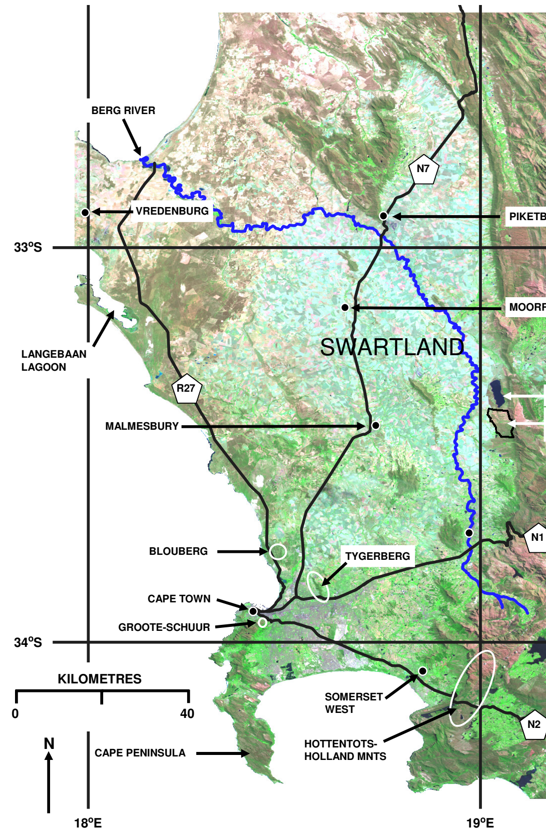

Fig. (2). Landsat 7 ETM false colour composite image of the study area, showing places mentioned in the text, major roads and towns, and the Berg River. Landsat imagery was not available for the area west of Vredenburg.

METHODS

Cost analyses were performed in Idrisi32 (©Clarklabs, Clark University, MA. USA.) using the integrated modules mentioned in the text below. Editing of the resulting corridor file was carried out in MapInfo Professional version 6.5 (©MapInfo Corporation; USA), due to its better vector file handling procedures. The land-cover map developed from Landsat 7 ETM imagery [13] was used as a basis for the friction image. The friction image was created by reclassing (RECLASS module) the land cover types to their chosen frictional values. To help speed up the analyses, the imagery (at an original resolution of 30m) was expanded to 60m. Road and river vector files at a scale of 1:50 000 (purchased from the Chief Directorate: Surveys and Mapping, Mowbray, South Africa) were rasterized onto the friction image. The frictional values assigned to each land- cover type are shown in Table **1**.

Frictional values are of an additive nature, so it "costs" the same to travel across two pixels with a value of one, as across one pixel with a value of two. Likewise, travelling across 100 pixels of frictional value one, costs the same as travelling across one with a frictional value of 100. So to get from point A to point B one travels by the pathway with the lowest sum of the pixels crossed.

Table 1. Frictional (Cost) Values Assigned to the Different Land-Cover Types Present within the Region Analyzed

Land-Cover	Frictional Value
Renosterveld	1
Fynbos/Thicket	2
Agriculture	100
Plantations	500
Urban	750
Open water, Dunes, Beach	1000
Ocean	Total barrier
Roads	5
Urban Roads	750
Rivers	10

Renosterveld patches were allocated a frictional value of one. This is taken as the base cost for movement across the landscape [15]. The other natural vegetation types (Fynbos and Thicket) were allocated a frictional value of two. This was because there are species common to Renosterveld and these other natural vegetation types. On the other hand, many Renosterveld plant endemics would be at a disadvantage, both from competition and from edaphic effects, when trying to use Fynbos or Thicket areas for dispersal. Most of the agricultural activity in this area is in the form of high intensity wheat growing, with few rest periods. Therefore the potential for perennial plants to disperse across these areas is very low. However, annual species may use them [*e.g.* 16]. There are also often "corridors" of uncultivated land between fields and along fence lines and tracks, which could be used for dispersal, but which do not show up at Landsat resolution. By far, the majority of WCR endemic plant species are perennials, and many of them are geophytes [5]. The potential for dispersal provided by the agricultural landscape is therefore very low, hence the relatively high value chosen. Plantations (although very rare in WCR) can be considered a special case of agricultural land, with a long-term harvesting period. While the trees are growing, the potential for species to disperse through plantations is very low, but after felling, there would be a period of one or more years during which time Renosterveld plants might be able to make use of them. Urban areas would generally have a very high resistance to dispersal, and this resistance would increase with time. Roads were allocated a frictional value of five. This value was used as some roadside verges are potentially good dispersal areas, but they suffer from random verge mowing and are often infested with alien species. Roads occurring within urban areas rarely have verges suitable for plant dispersal and were masked out. Many of the minor roads have no verge as such, the agriculture extending right to the edge of the road. Rivers were given a frictional value of ten. While riparian areas may be useful for the dispersal of generalist species, they often support a different vegetation community to areas away from rivers. They may however, be suitable habitats for pollinators, such as birds and insects. The value of –1 given to the ocean, indicates a complete barrier to dispersal.

While the friction image gives a general view of the natural compatibility of the landscape (Fig. **3**), it is too complex to analyze subjectively. Therefore individual cost images for every fragment of interest have to be developed. The cost image calculates, for each source fragment, the "cost" of traveling to every pixel on the image and allocates to that pixel its cost. These cost images were created using the "Costgrow" option of the "COST" module. Despite the analysis of [13] being confined to fragments of greater than three hectares, this still resulted in 1889 natural vegetation fragments being identified, which was far too many to analyze individually. The cost analyses were therefore confined to three groups of fragments. The first included all the sites identified by McDowell [9], plus the Rondeberg (sampled by [17]). The second consisted of all natural vegetation fragments of greater than 50 ha falling within the historically defined limits of WCR [18-20]. The final group was all natural vegetation fragments of greater than 25 ha defined as being high probability (geological/pedological) Renosterveld [12]. Note that while these 202 fragments were the ones used as points of origin for each cost image, the other fragments remained in the friction image to be used as "stepping stones" across the landscape.

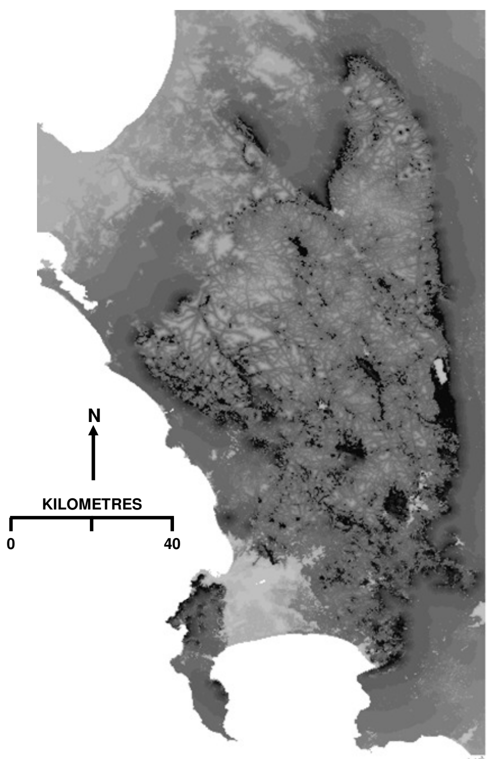

Fig. (3). Friction image of the western lowlands, as developed for the dispersal of Renosterveld plant species. Shading is approximately logarithmically related to dispersal cost, with black equating to the base dispersal cost of one (*i.e*. Renosterveld fragments), and white (the ocean) being a total barrier.

Least-cost pathways were mapped between the 202 chosen fragments and each of eight boundary lines (Fig. **4**) using the "PATHWAY" module. The pixel with the lowest value on the end line becomes the end point. The eight adjoining pixels are then compared and the pixel with the lowest value becomes the next point. This is continued until the line reaches the source pixel [15].

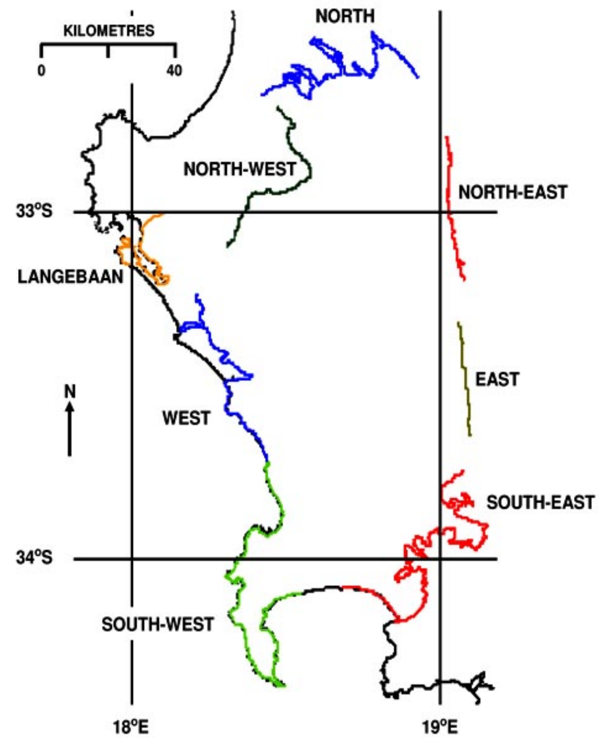

Fig. (4). The eight end-points used for developing the pathways.

The eight pathways produced from each of the cost images (1616 pathways in total) were combined to produce a corridor map. Each corridor section was assigned a value equivalent to the number of paths making up that section of the corridor. A "section" is defined as the line occurring between intersections. Once this had been done, the points where these corridor lines reached the boundary lines (84 points in total) were treated as points of origin, and the whole process repeated, except that pathways were only constructed to the seven boundary lines that were not abutting the point of origin. These cross- Renosterveld "corridor" lines were added to the corridor lines from the fragment source images.

RESULTS

Due to minor calculation differences inherent in an image as large as the one used (7 354 900 pixels), combining the pathway images often led to several corridor lines running parallel to each other through the larger fragments. These lines were combined into a single line to enhance legibility and were given a weight equivalent to the sum of the lines. The important factor to note is that the corridors preferentially exist around the perimeter of the Renosterveld region, rather than crossing it (Fig. **5**). Although the frictional values used in this study did not identify any direct connections between the Peninsula fragments and those of the Tygerberg or Blouberg fragments, the finer-scale local study of [21] identified a coastal corridor between Groote Schuur and Blouberg.

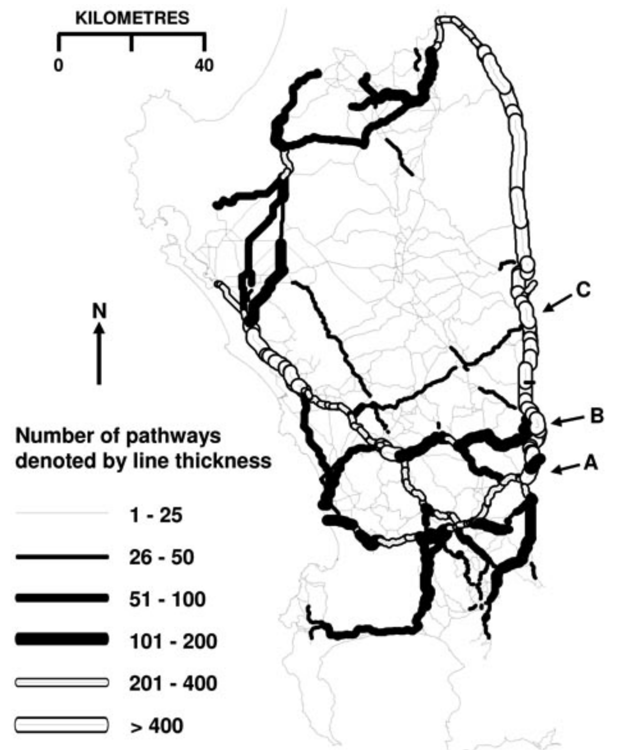

Fig. (5). Dispersal corridors identified by the cost analysis of West-Coast Renosterveld.

DISCUSSION

This technique was used by [21] to determine natural vegetation corridors occurring within the Greater Cape Town area. In that study the authors used a system whereby nodes (points where corridor lines overlap) were created, and a weight, based upon the number of paths intersecting that node was assigned to that node. Nodes with high scores indicated locations of high ecological importance which need to be conserved. Due to the large number of intersections occurring in this study, a system of weighting the corridor lines themselves was used instead.

Our aim here is not to provide a definitive description of dispersal pathways for all Renosterveld species. It is rather to indicate how this method can be used to identify general patterns of connectivity within a (large) complex and ecologically hostile landscape, and to help identify areas that are likely to be isolated from the general population. It could be used to provide overviews of, for example, patterns of connectivity in developing countries where ground data are limited and difficult to access. Our study area only covers an extent of 184 km (N–S) by 78 km (E–W). One only has to examine Fig. (**1**) to realize that manually trying to identify potential dispersal routes using all the fragments would be difficult, if not impossible. Even when the image was blown up to cover two A0 sheets (as was done for ground-truthing purposes), the smaller fragments were often lost in the background. The study of [5] identified fragments down to single pixel size. These would be impossible to see, and one could easily imagine 50 ha or larger fragments becoming lost in the background of country-wide analyses.

An advantage of this method is that same land-cover types are treated equally across the whole area (unless the friction image specifies regional differences). Manual analyses result in sub-conscious differences in the weighting of the same land-cover types, even when there is no ecological reason for doing so. Of course, one might argue that, for example, a single wheat field 100 m wide has a smaller barrier effect than many adjacent fields stretching across several kilometers. Nevertheless, the consistent frictional weightings of each type of land-cover pixel should ameliorate this effect.

Compare our corridor analysis of WCR with that produced by [5]. They identified a "corridor" (their "coastal gradient"), which approximates the southern-most (A) east-west pathway shown in Fig. (**5**). While this pathway is of importance, particularly for linking the natural vegetation on the Cape Peninsula with other natural areas, the more northerly (B) of the two thick corridor lines is probably more important for Renosterveld species, and also supplies an alternative to the southern-most corridor, which is increasingly coming under threat from urban expansion. A further disadvantage of the southern-most corridor (A) is that more of it is situated on Quaternary sands, which are often incompatible with Renosterveld plant species, (and in some cases, their pollinators [22]) than is the case with the northern corridor. In fact, the thinner corridor line (C) has the most likelihood of providing an east-west dispersal route for those species with a low range of edaphic tolerance.

Although the procedure we used indicates the "cost" of traveling across the different land-cover types, we did not take into account other factors that act independently of land-cover. Such factors include wind, for wind-dispersed propagules and slope for the more terrestrially bound vectors. Our study area receives predominantly north-westerly winds in winter, and south-easterly winds in summer. Topographically it is predominantly flat. If individual species were being examined, these factors could have been incorporated into the analysis.

A number of objections may be raised as to the validity of this technique, the most important of which is the frictional values ascribed to the land cover types. Over relatively small areas, such as that described by [21], detailed information on environmental conditions may be collected and a more definite goal may be ascribed, thus making frictional allocations easier. With larger areas, such as the one described here, this is more difficult. For example, although WCR is confined to the more nutrient rich soil types [7], there are actually several types of substrate, each with its own characteristics e.g. shales, granites, loamy sand [23-25]. In addition, despite the relatively small area covered by this vegetation type, there is a steep increase in rainfall as one moves from the north-west to the south east (<300mm to >1200mm [26]). An analysis of the distribution of the rare and endangered plant species [27] suggests that within this area, many of the endemics have microhabitat requirements that do not show up, even at the 1:50 000 scale. In addition to these apparent micro-habitat requirements, analyses of the dispersal distances of many Fynbos (including Renosterveld) endemics, has shown that their seed dispersal distances are often very small (<10m) [28], and often restricted to the period immediately after a burn [29], which may only occur at 10 to 25 or more year intervals. It has even been suggested [14] that a short dispersal distance benefits the species, as a dense community of insect pollinated species will attract pollinators more effectively than widely dispersed individuals. For these species, dispersal corridors are of little use, except for pollinator dispersal and the possible mixing of genetic material from different populations. We acknowledge that, given a specific task, one would incorporate as much information as possible into the frictional allocation, and possibly experiment with different values. With the information and resources available to us, we chose values that we considered reasonably reflected an average potential for dispersal, relative to "pure" Renosterveld. Based on our local knowledge, we believe that the general pathway pattern produced, does reasonably reflect the dispersal potential within the area examined.

A current disadvantage is the extended use of computer time required to complete each analysis. Although the cost analyses themselves can be left to run sequentially in macro mode, combining the resulting corridors and assigning a total to each line section is a lengthy process that currently requires human intervention, although this may not be necessary during preliminary analyses. Computer time could be reduced to a certain extent by using the alternative "Costpush" option of the "COST" module. This option does not allow for the presence of a total barrier (such as for the ocean or areas outside the study area), although such areas could be given very high values. Restricting the frictional values to "byte" sized values (0 to 255) would further help speed up the processing. Increases in the processing speed of personal computers will also help speed analyses, and there is also the potential for the development of a dedicated program (along the lines of C-Plan for reserve analyses).

CONCLUSION

We have shown in this exercise that by making use of the tools used by civil engineers it is possible to obtain a relatively objective view of fragmented landscapes, as humans perceive them to be, in terms of eco-friendliness. We acknowledge that this method remains subjective to the extent that the costs assigned to the different land-cover types are determined by humans. Similarly the same land-cover type can vary enormously in terms of its ecological compatibility for different organisms. The Landsat imagery used is provided at a nadir resolution of 28.5m, which is too coarse to identify the quality of road verges, field verges, strips of natural vegetation across fields etc. These are also problems that beset those who use a subjective "eye-balling" procedure. Nevertheless, the method described here can take into account complicated mosaics of land cover over large areas.

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