

Target-based site prioritization under climate change using quadratic network flow

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1 Introduction

Currently, 14.9% of terrestrial area is a part of the global protected area network (UNEP-WCMC 2018). However, most of this areas have not been created using prioritization tools developed to maximize species or ecosystems conservation based on current biodiversity patterns (Rodrigues et al. 2004; Jenkins et al. 2015). The situation is even worst when we take into account that the range of species will change over time (Araújo et al. 2004; Chen et al. 2011; Lenoir et al. 2008; Regos et al. 2016), were several species that are now being protected by these areas might not be protected in the future because of the climate crisis (Alagador, Cerdeira, and Araújo 2014; Araújo et al. 2004).

Despite the concern about protected area planning, a review Jones et al. (2016) shows that more than 90% of the prioritization planing studies that try to incorporate climate change, only take two time steps into account, current climate and the last step of climate. Currently, two of the most used tools for conservation planning are Prioritize and Zonation (Di Minin et al. 2014; Hanson et al. 2019). Zonation can be used for conservation prioritization under climate change as conservation features may be explicitly linked through interaction. This allows for simultaneous prioritization of a species current range, its modelled future range, and the connectivity between the two limited by a species' capacity to disperse.

	Network flow	Zonation	Migclim	Prioritizr
Considers more than 2 time-slices	Yes	No	Yes	No
Can add species to the solutions afterwards	Yes	No	Yes	No
Keep track of species dispersal routes	Yes	Yes	Yes	No
Solves for conservation targets	Yes	Yes	No	Yes
Considers cost as part of the solution	Yes	Yes	No	Yes

However, in order for the species to move from areas were they are currently protected to the future protected areas, their route has to be protected as well, that is the biological corridors that they will use (Nuñez et al. 2013; Rosenberg, Noon, and Meslow 1997). Thus, the planification and creation of those biological corridors correspond to adaptive measures to environmental changes that would mitigate the impacts of the climate crisis (Hannah et al. 2007). In that context, biological corridors should consider effects of climate crisis, changes in land use and habitat fragmentation, in order to evaluate the factibility of the species reaching future available habitat.

There have been several approaches trying to model biological corridors. Local approaches have focus just in one or a few species (Alagador, Cerdeira, and Araújo 2014; Cushman et al. 2013; Gregory et al. 2014) or group of species (Beier, Majka, and Bayless 2007; Phillips et al. 2008; Williams et al. 2005), not being able to be use for planning for lack of species or be in confined spaces, respectively. A continental approach was made by Lawler et al. (2013), who modelled biological corridors in the Americas. Even when that model was made for close to 3,000 species did not consider species dispersal speed or use the information to build priority areas. Among these articles, the work of Phillips et al. (2008), incorporates the use of the Network Flow optimization method (Ahuja, Magnanti, and Orlin 1993) in order to solve the problem expressed by Williams et al. (2005), generating a solution 33% more efficient than previous optimization methods. This makes this methodology one of the most promising ways of solving conservation planning problems through the use of biological corridors.

In its traditional use, Network flow gives the best possible solution given constrains (Phillips et al. 2008). If



Figure 1: Map of Southamerica, the darkened area is the area where the prioritization was performed

we looked at the solution for a species in a raster, every cell would have a value of either one or zero, where one would be a cell necessary for the conservation of the species or a zero if it is not necessary. This best solution, however, only represents one of the possible solutions to conserve a species, and does not give us any alternatives. In this research we present Quadratic Cost Network Flow as an alternative solution, where for every species we would still get a value of one if the cell is irreplaceable for the solution, zero if that cell is not needed, and an intermediate value for cells that are one of many alternative solutions for a given species, this is, for every cell we have an irreplaceability index. Spatial planning is a complex endeavour where agendas and/or needs evolve rapidly and several alternative suboptimal solutions might be needed in order to navigate this complex decisions.

In this article we present a new method of working with network flow on conservation planning using quadratic costs, while at the same time comparing its results and implications with traditional network flow and zonation, using the Northern Tropical Andes ecoregion as an example.

2 Methods

2.1 Area

The studied area was the Northern Tropical Andes, consisting of the countries of Colombia, Venezuela and Ecuador, with a buffer of 200 kilometres around land areas.

The studied area is shown in figure 1 and it encompasses 3,632,762 square kilometres

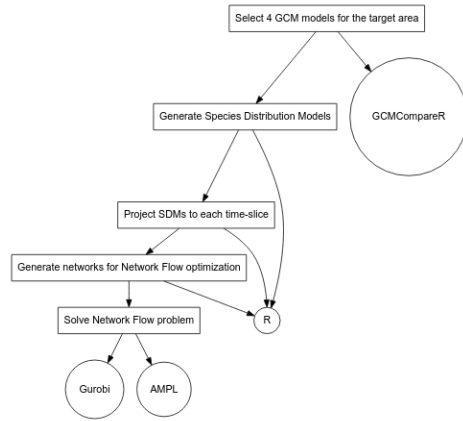


Figure 2: All the steps and programs used in the Optimization

2.2 Species

671 species of plants were used for the model, only endemic species were used in this study. A list can be found in the supplementary materials

2.3 Global circulation models

Global Circulation Models (GCMs) are predictive models that use fluid models. . . In order to select 4 GCMs, GCMComparer application was used 2. Distribution models were generated for each GCM using the Dismo Package in R. Then, each model was projected as a binary response (presence-absence) for all decades form 2000 (present) to 2070 completing 8 time slices for each species.

For each species, a network of dispersion into each time-slice was generated using the QuadCostAmpl package, and finally we solved for Network Flow using the AMPL software using the Gurobi solver

Four GCM models were selected to project the species distribution using the GCMcompareR shiny app (Fajardo et al. 2018), we followed the story-lines approach (Zappa and Shepherd 2017) and selected a GCM warmer and wetter, warmer and dryer, colder and wetter, and colder and dryer than the ensemble. The selected models where cc, cn, la, mp al the process is shown in in figure 2.

2.4 Niche modelling

For each species the species distribution model was fit using the dismo package (Hijmans et al. 2017), using 50,000 random background points and the maxent algorithm (Phillips, Anderson, and Schapire 2006; Merow, Smith, and Silander Jr 2013)

2.5 Model Description

This model was developed based on the notion of non-overlapping dispersal chains (Williams et al. 2005), and instead of having a binary solution (to protect or not protect an area), the result will be an index of importance going from zero to one. Here, zero means that there are no chains passing by that spacial point that go from the source to the final destination, and one is a point where chains have to pass through to reach the desired flow. In order to do this, we follow Network-flow methods (Ahuja, Magnanti, and Orlin 1993) to model the survival and dispersion of species along the space and time, using species distribution models and quadratic flow costs to split the flow evenly across alternative paths. Therefore, the resulting flow across an arc is high only if there are few alternatives to use that edge to achieve the target flow. Even when model takes into account protected areas (cost zero) and human habitat such as cities (cost infinite) in the decision making, both were not included in this exercise to simplify the examples. This is a generalist

model which only needs the distribution model of the species projected to each time slice and the maximum dispersal distance for each species.

2.5.1 Model Formulation

The objective is to minimize the cost

minimize
Quadcost

$$Quadcost = \sum_{i=1}^n (Cost \times Flow_t)^2$$

subject to

$$\text{Initial Flow} = \sum_{i=1}^n Flow_{t_1} = \text{Target paths}$$

$$\text{Final Flow} = \sum_{i=1}^n Flow_{t_{final}} = \text{Target paths}$$

$$\text{Flow capacity} = \sum_{i=1}^n Flow_{(i,t)} \leq capacity_{(i,t)}$$

2.6 Network generation

In order to generate the networks the QuadCostAmpl package was used (Corcoran and Fajardo 2019)

2.7 Linear Network Flow

Model

2.8 Quadratic Network Flow

2.9 Zonation

Results

- **For methods:** Since one of the main objectives of prioritization methods is to rank the cells within an area, we used Spearman's rho correlation, that estimates the rank-based measure of association. We also calculated a local Spearman correlation on a matrix of five by five cells, in order to figure out if there are some important

There are two ways of trying to look at the results, as a continuous layer, as in figure 3, or as a binary solution as in fig 4, where the cells in red are the top 10% ranked cells to be protected. At first glance, the three algorithms have very similar results. In all three methods the Andes mountains appear to have the highest priorities in particular the Northwest Andean montane forests, Eastern Cordillera Real montane forests, Venezuelan Andes montane forests, Cordillera Oriental montane forests, and the Cauca and Magdalena Valley montane forests, outside of the Andes mountains the ecoregions that have the highest priorities are Guianan Highlands moist forests, Pantepui forests & shrub-lands and Cordillera La Costa montane forests. Furthermore, when we look at the top 10% cells selected by the algorithms (Figures 4 and 5), we see that of all the cells that were selected at least by one algorithm 62.91% of the cells were selected by all three algorithm, which show the level of concordance between cells, 18.85% were selected by two of the algorithms and only 18.24% of the cells selected were chosen by only one of the methods.

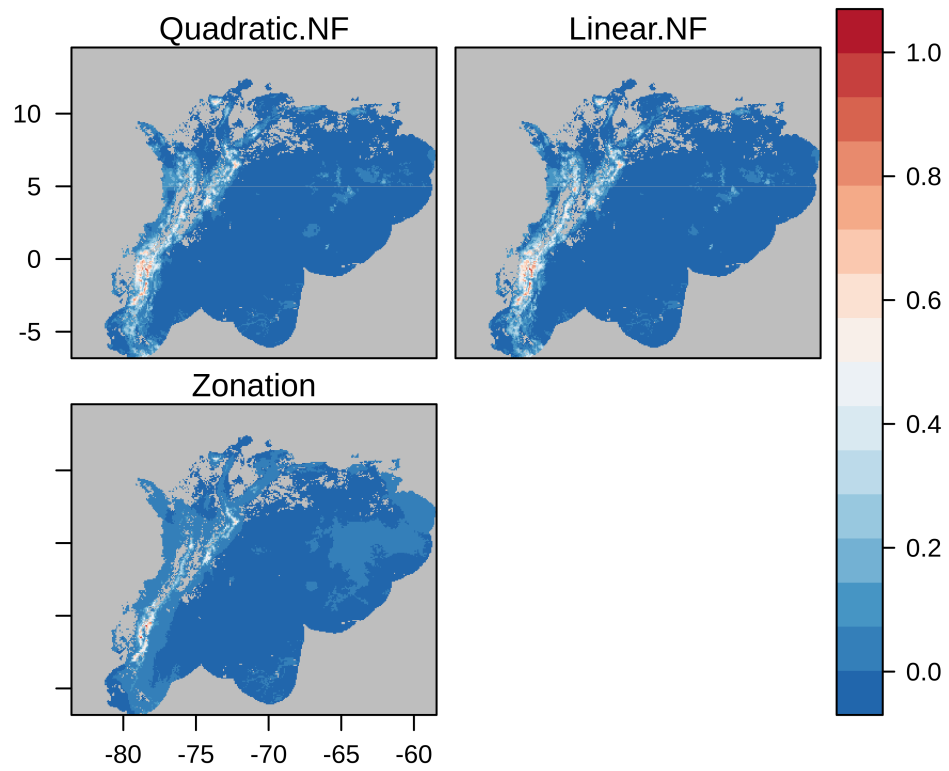


Figure 3: Continuous results of the three algorithms, the highest the value the higher the priority, all values go from 0 to 1.

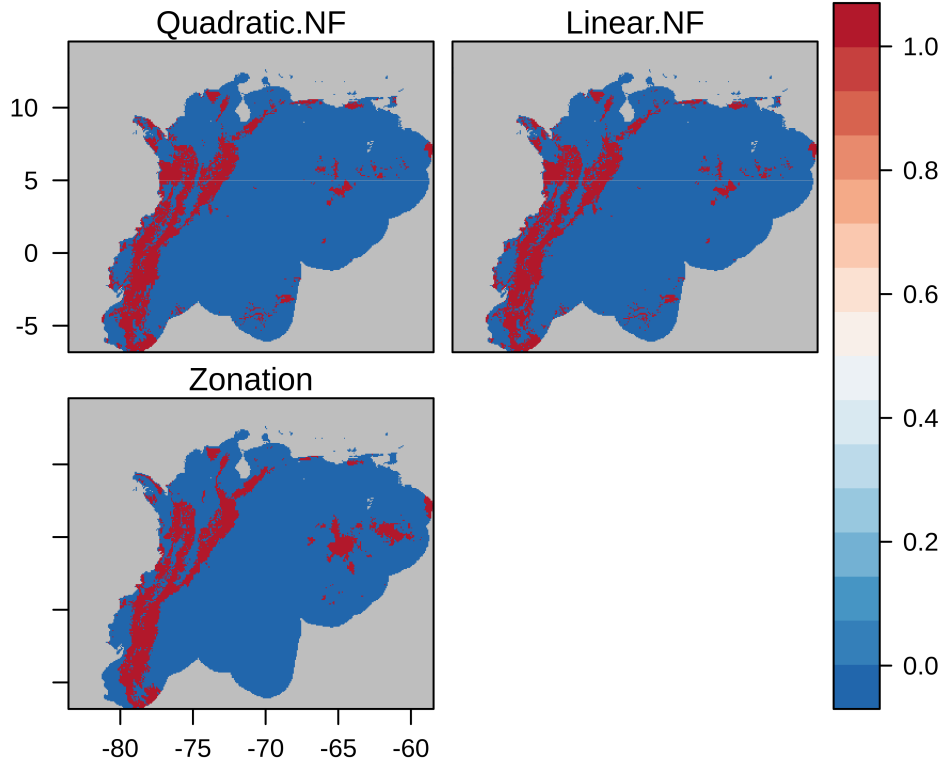


Figure 4: Binary solution for the cells with the top 10% value of ranked priority

However, when we look at the Spearman correlation (table 1), of all three methods we start seeing some important differences, where Quadratic and Linear Network flow have a spearman correlation of 0.92, but both methods have a smaller correlation with zonation, with Quadratic Network Flow having a higher correlation of 0.669, vs linear network flow having a correlation of 0.624 with Zonation. When we look at the local correlation plots (figure 6), we see that for the most part, the local correlations are all mostly positive, specially between both Network Flow algorithms. There are some blue areas in the figure, when comparing those priorities with zonation. Representing some big discrepancies in local prioritization, that is mostly localized

when we look at the box-plot of local correlation values (figure 7), we see that the lower whiskers in the comparison of both Network Flow methods with Zonation, are below zero

- **For discussion:** One of the main problems at comparing Network Flow vs Zonation, is that Zonation will give a rank to each and every cell in the study area, which is not true for Network Flow. It comes as no surprise that Quadratic Network flow has a higher correlation with Zonation than Linear Network flow, the intended result of quadratic network flow being more similar to zonation than linear network flow.

2.9.1 Efficiency comparison (Number of cells)

In this example when we calculate the top 10% of protected cells for Quadratic Network Flow we get 22,671 cells, 22,586 cells for linear Network Flow, and 22,671 cells for Zonation.

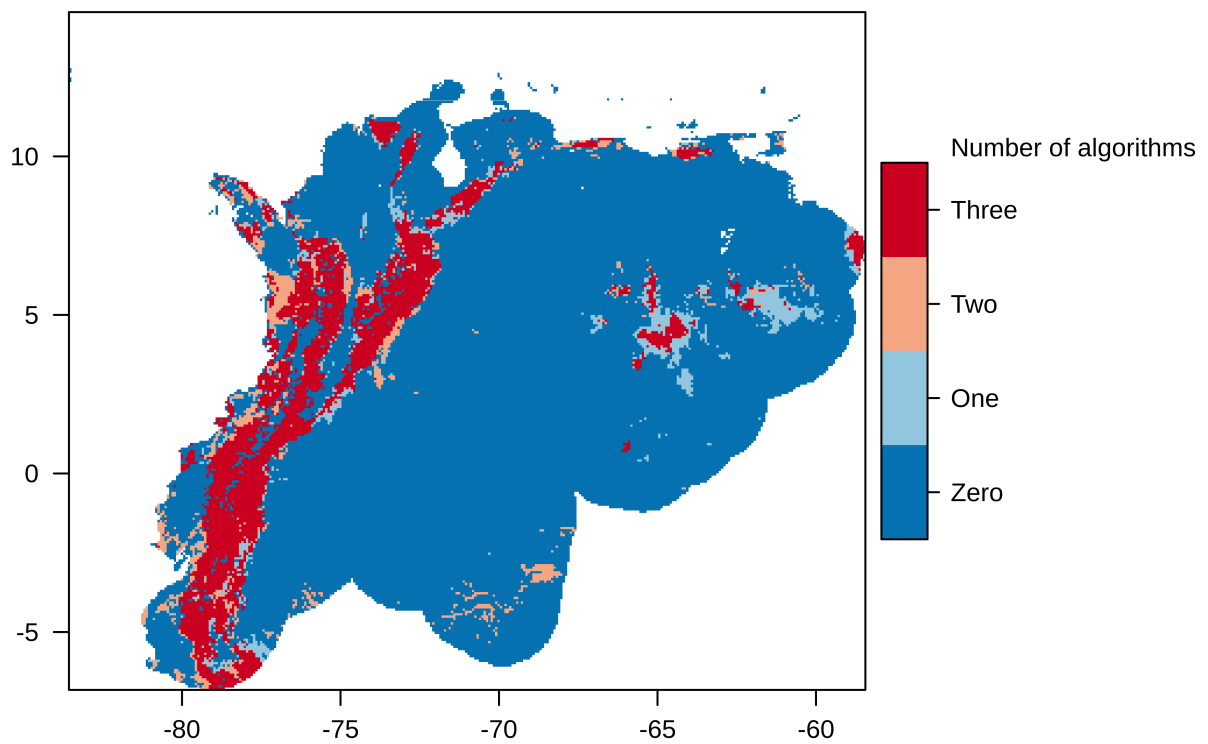


Figure 5: This map shows how many algorithms selected each cell

Table 1: Spearman correlation between the rank of the cells of all three methods

rowname	Linear.NF	Quadratic.NF	Zonation
Linear.NF	NA	0.9211996	0.6241322
Quadratic.NF	0.9211996	NA	0.6690281
Zonation	0.6241322	0.6690281	NA

2.9.2 Correlation comparison (Spearman)

3 Discussion

Disclosure/Conflict-of-Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

The statement about the authors and contributors can be up to several sentences long, describing the tasks of individual authors referred to by their initials and should be included at the end of the manuscript before the References section.

Acknowledgments

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4 Supplemental Data

Supplementary Material should be uploaded separately on submission, if there are Supplementary Figures, please include the caption in the same file as the figure. LaTeX Supplementary Material templates can be found in the Frontiers LaTeX folder

5 References

Figures

6 Supplementary materials

6.1 List of species

The species used for the solution were the following:

Aa maderoi, Abutilon ibarrense, Achyrocline crassiceps, Aciachne flagellifera, Aechmea drakeana, Aegiphila pennellii, Aequatorium sinuatifolium, Aequatorium verrucosum, Aetheolaena involucrata, Aetheolaena linguata, Ageratina asclepiadea, Ageratina dendroides, Ageratina gynoxoides, Ageratina pseudochilca, Ageratina theaeifolia, Ageratina vacciniaefolia, Agouticarpa grandistipula, Agrostis boyacensis, Agrostis foliata, Agrostis trichodes, Aiphanes grandis, Altensteinia virescens, Amazilia castaneiventris, Anagallis foemina, Anastrophylum nigrescens, Andigena laminirostris, Anomobryum prostratum, Anotomys leander, Anredera brachystachys, Anthopterus schultzeae, Anthurium aristatum, Anthurium carchiense, Anthurium cordiforme, Anthurium

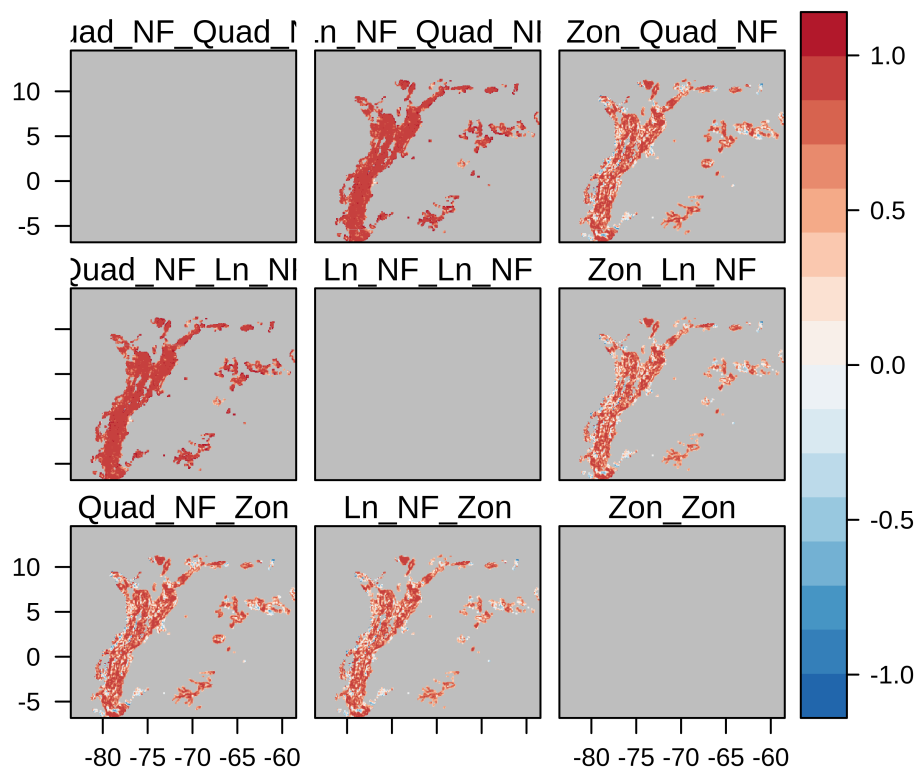


Figure 6: Box plot of local correlations between all three different methods of prioritization

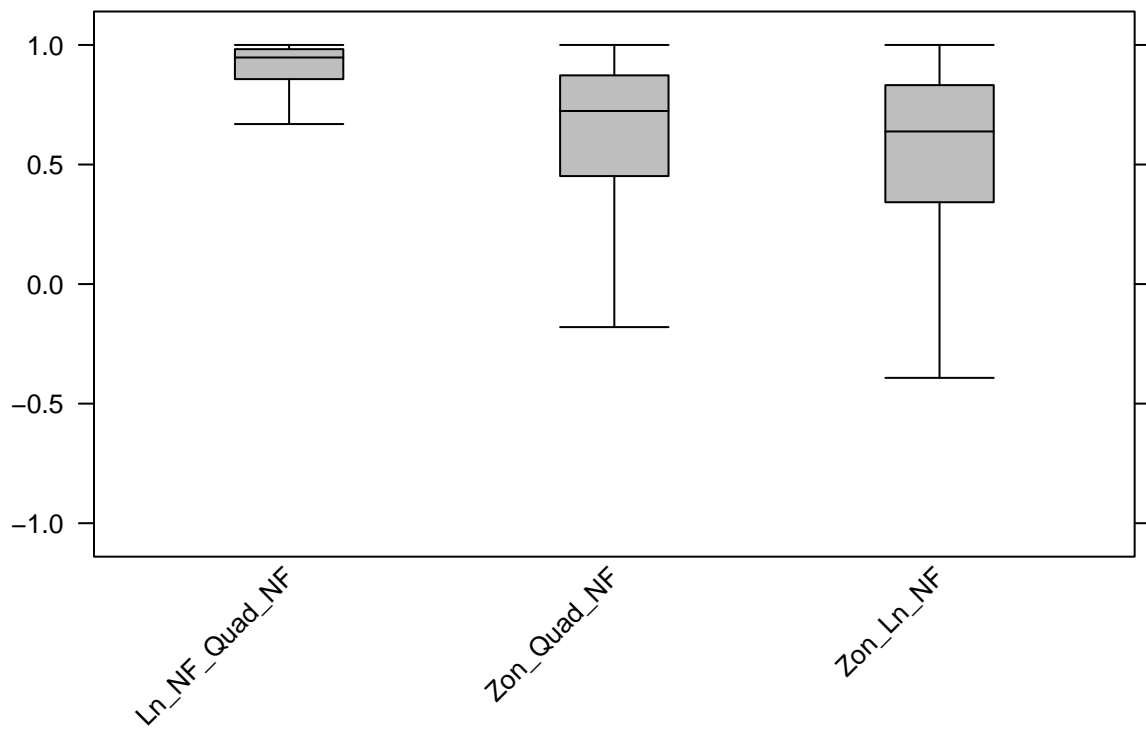


Figure 7: Box plot of local correlations between all three different methods of prioritization

flavolineatum, *Anthurium giganteum*, *Anthurium gualeanum*, *Anthurium herthae*, *Anthurium lancea*, *Anthurium membranaceum*, *Anthurium morae*, *Anthurium palenquense*, *Anthurium pallatangense*, *Anthurium pedunculare*, *Anthurium pendulispadix*, *Anthurium phyllobaris*, *Anthurium rimbachii*, *Anthurium rugulosum*, *Anthurium wattii*, *Aphanactis jamesoniana*, *Aphanactis olgaardii*, *Aphanactis piloselloides*, *Aragoa abietina*, *Aragoa cundinamarcensis*, *Aragoa occidentalis*, *Arcytophyllum aristatum*, *Arenaria venezuelana*, *Aristeguietia glutinosa*, *Arracacia moschata*, *Arremon phaeopleurus*, *Astragalus geminiflorus*, *Astragalus sprucei*, *Atlappetes flaviceps*, *Atlappetes leucopis*, *Atractus crassicaudatus*, *Atractus lasallei*, *Axinaea meriania*, *Axinaea sodiroi*, *Azorella aretioides*, *Azorella cuatrecasasii*, *Azorella pedunculata*, *Baccharis revoluta*, *Baccharis rupicola*, *Baccharis teindalensis*, *Badilloa salicina*, *Bangsia aureocincta*, *Bangsia edwardsi*, *Bangsia rothschildi*, *Bartsia laticrenata*, *Bartsia orthocarpiflora*, *Bartsia santolinifolia*, *Bartsia stricta*, *Bauhinia stenantha*, *Begonia tiliifolia*, *Belloa radians*, *Berberis goudotii*, *Berberis hallii*, *Berberis rigidifolia*, *Berberis verticillata*, *Besleria angustiflora*, *Blakea glandulosa*, *Blakea hispida*, *Blakea oldemanii*, *Blakea rotundifolia*, *Bolborhynchus ferrugineifrons*, *Bomarea glaucescens*, *Bomarea linifolia*, *Bomarea patacensis*, *Bomarea uncifolia*, *Bractia andina*, *Brachyotum alpinum*, *Brachyotum confertum*, *Brachyotum fictum*, *Brachyotum gleasonii*, *Brachyotum harlingii*, *Brachyotum jamesonii*, *Brachyotum strigosum*, *Brayopsis colombiana*, *Breutelia squarrosa*, *Breutelia trianae*, *Browneopsis disepala*, *Brugmansia aurea*, *Brunellia boqueronensis*, *Brunellia colombiana*, *Bucquetia glutinosa*, *Buddleja pichinchensis*, *Burmeistera montipomum*, *Calamagrostis aurea*, *Calamagrostis effusa*, *Calamagrostis fibrovaginata*, *Calamagrostis guamanensis*, *Calamagrostis mollis*, *Calamagrostis podophora*, *Calceolaria dilatata*, *Calceolaria ferruginea*, *Calceolaria hyssopifolia*, *Calceolaria lamiifolia*, *Calceolaria pedunculata*, *Calceolaria purpurascens*, *Calceolaria rosmarinifolia*, *Calliergonella cuspidata*, *Campylopus argyrocaulon*, *Campylopus cleefii*, *Campylopus cucullatifolius*, *Campylopus edithae*, *Campylopus incertus*, *Campylopus pittieri*, *Campylopus subconcolor*, *Carex amicta*, *Casearia mexiae*, *Castilleja nubigena*, *Castratella piloselloides*, *Centradeniastrum album*, *Centropogon aequatorialis*, *Centropogon baezanus*, *Centropogon glabrifilis*, *Centropogon medusa*, *Centropogon nigricans*, *Centropogon subandinus*, *Cerastium floccosum*, *Ceratostema alatum*, *Cestrum peruvianum*, *Chalcostigma heteropogon*, *Chorisodontium speciosum*, *Chromolaena bullata*, *Chusquea subulata*, *Cinclodes excelsior*, *Cistothorus apolinari*, *Cistothorus meridae*, *Citharexylum sulcatum*, *Clavija eggersiana*, *Clethra crispa*, *Clinopodium nubigenum*, *Clinopodium taxifolium*, *Clinopodium tomentosum*, *Clusia callejasii*, *Coespeletia moritziana*, *Coespeletia spicata*, *Coespeletia thyrsiformis*, *Coespeletia timotensis*, *Colignonia pentoptera*, *Columnnea albiflora*, *Columnnea capillosa*, *Columnnea ciliata*, *Columnnea eubractea*, *Conirostrum rufum*, *Conyza cardaminifolia*, *Conyza trihecatactis*, *Coursetia gracilis*, *Coussarea pilosiflora*, *Cranichis antioquiensis*, *Cranioleuca hellmayri*, *Critoniopsis occidentalis*, *Critoniopsis palaciosii*, *Critoniopsis sodiroi*, *Cronquistianthus niveus*, *Croton elegans*, *Croton rimbachii*, *Cryptotis equatoris*, *Culcitium nivale*, *Cyanolyca pulchra*, *Cynanchum microphyllum*, *Dalea humifusa*, *Dasyphyllum popayanense*, *Dendrophorbium lloense*, *Diglossa gloriosa*, *Diglossa gloriosissima*, *Diglossa indigotica*, *Diplostephium alveolatum*, *Diplostephium bicolor*, *Diplostephium cayambense*, *Diplostephium cinerascens*, *Diplostephium ericoides*, *Diplostephium frontinense*, *Diplostephium glandulosum*, *Diplostephium hartwegii*, *Diplostephium ochraceum*, *Diplostephium phyllicoides*, *Diplostephium revolutum*, *Diplostephium rhododendroides*, *Diplostephium rhomboidale*, *Diplostephium rupestre*, *Diplostephium schultzii*, *Diplostephium spinulosum*, *Diplostephium tenuifolium*, *Diplostephium tolimense*, *Diplostephium violaceum*, *Diplostichum longirostre*, *Distichia acicularis*, *Ditrichum submersum*, *Draba aretioides*, *Draba hallii*, *Draba obovata*, *Draba splendens*, *Draba spruceana*, *Dracula sodiroi*, *Drepanocladus exannulatus*, *Drymonia crenatiloba*, *Drymonia laciniosa*, *Dysithamnus occidentalis*, *Elaphoglossum antisanae*, *Elaphoglossum heliconiifolium*, *Elaphoglossum yatesii*, *Elasis hirsuta*, *Elatine ecuadoriensis*, *Elleanthus gastroglottis*, *Elleanthus petrogeiton*, *Epidendrum englerianum*, *Epidendrum marsupiale*, *Epidendrum pallatangae*, *Epidendrum pichinchae*, *Epidendrum porphyreum*, *Eragrostis condensata*, *Erigeron ecuadoriensis*, *Eriocnemis cupreovertris*, *Eriocnemis derbyi*, *Eriocnemis mosquera*, *Eryngium humboldtii*, *Espeletia argentea*, *Espeletia barclayana*, *Espeletia batata*, *Espeletia boyacensis*, *Espeletia brassicoidea*, *Espeletia cleefii*, *Espeletia congestiflora*, *Espeletia conglomerata*, *Espeletia frontinoensis*, *Espeletia grandiflora*, *Espeletia hartwegiana*, *Espeletia killipii*, *Espeletia lopezii*, *Espeletia murilloi*, *Espeletia pycnophylla*, *Espeletia schultesiana*, *Espeletia schultzii*, *Espeletia semiglobulata*, *Espeletia summapacis*, *Espeletia tunjana*, *Espeletia uribei*, *Espeletiopsis colombiana*, *Espeletiopsis corymbosa*, *Espeletiopsis pannosa*, *Espeletiopsis petiolata*, *Eudema nubigena*, *Euphonia concinna*, *Festuca andicola*, *Festuca chimborazensis*, *Festuca glumosa*, *Festuca subulifolia*, *Festuca vaginalis*, *Fuchsia ampliata*, *Fuchsia 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dus, *Gasteranthus quitensis*, *Gaultheria cordifolia*, *Geissanthus argutus*, *Genista monspessulana*, *Gentianella cerastioides*, *Gentianella cernua*, *Gentianella corymbosa*, *Gentianella foliosa*, *Gentianella hirculus*, *Gentianella hyssopifolia*, *Gentianella nummulariifolia*, *Gentianella rapunculoides*, *Gentianella rupicola*, *Geonoma divisa*, *Geranium maniculatum*, *Geranium multiceps*, *Geranium multipartitum*, *Glaucidium nubicola*, *Gongylolepis jauaensis*, *Grallaria alleni*, *Grallaria flavotincta*, *Grallaria milleri*, *Grallaria rufocinerea*, *Grallaricula lineifrons*, *Grallaricula loricata*, *Grosvenoria hypargyra*, *Grosvenoria rimbachii*, *Gustavia longifuniculata*, *Gustavia serrata*, *Guzmania jaramilloi*, *Guzmania lehmanniana*, *Guzmania vanvolxemii*, *Guzmania wittmackii*, *Gynoxys acostae*, *Gynoxys hirsuta*, *Gynoxys laurata*, *Gynoxys miniphylla*, *Gynoxys parvifolia*, *Gynoxys pendula*, *Gynoxys sodiroi*, *Gynoxys stuebelii*, *Gynoxys tolimensis*, 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lyman-smithii*, *Miconia aguirrei*, *Miconia biappendiculata*, *Miconia chlorocarpa*, *Miconia dielsii*, *Miconia glandulistyla*, *Miconia hymenantha*, *Miconia nodosa*, *Miconia pernettifolia*, *Miconia pichinchensis*, *Miconia psychrophila*, *Miconia scutata*, *Miconia summa*, *Miconia turgida*, *Mimosa quitensis*, *Mimosa townsendii*, *Mona meridensis*, *Monnina crassifolia*, *Monnina equatoriensis*, *Monnina obtusifolia*, *Monnina pseudopilosa*, *Monnina revoluta*, *Monnina sodiroana*, *Monnina tenuifolia*, *Monticalia arbutifolia*, *Monticalia peruviana*, *Monticalia vaccinioides*, *Morella singularis*, *Muscisaxicola alpinus*, *Mutisia grandiflora*, *Mutisia microphylla*, *Mutisia sodiroi*, *Myioborus albifrons*, *Myrrhidendron glaucescens*, *Myrsine panamensis*, *Niphogeton azorelloides*, *Niphogeton glaucescens*, *Niphogeton josei*, *Notopleura marginata*, *Nototriche jamesonii*, *Nototriche phyllanthos*, *Odontoglossum hallii*, *Odontophorus atrifrons*, *Odontophorus melanonotus*, *Oncidium serratum*, *Opuntia soederstromiana*, *Oreobolus cleefii*, *Oreopanax corazonensis*, *Oreopanax ecuadorensis*, *Oreopanax ellsworthii*, *Oreopanax grandifolius*, *Oreopanax mutisianus*, *Oreopanax nigrum*, *Oreopanax palamophyllum*, *Oreopanax ruizanus*, *Oreothraupis arremonops*, *Oreotrochilus chimborazo*, *Ossaea sessilifolia*, *Oxypogon guerini*, *Paepalanthus alpinus*, *Paepalanthus karstenii*, *Paepalanthus lodiculoides*, *Palicourea prodiga*, *Palicourea sodiroi*, *Palicourea subalatoidea*, *Pappobolus imbaburensis*, *Paspalum hirtum*, *Passiflora adulterina*, *Passiflora crispolanata*, *Passiflora cuatrecasii*, *Passiflora jamesonii*, *Passiflora roseorum*, *Passiflora trinervia*, *Pedicularis incurva*, *Pentacalia abietina*, *Pentacalia americana*, *Pentacalia arbutifolia*, *Pentacalia flosfrangens*, *Pentacalia guadalupe*, *Pentacalia ledifolia*, *Pentacalia nitida*, *Pentacalia pulchella*, *Pentacalia reissiana*, *Pentacalia vaccinioides*, *Pentacalia vernicosa*, *Pentagonia grandiflora*, *Peperomia fuscipunctata*, *Peperomia miqueliana*, *Pernettya hirta*, *Phalcooboenus carunculatus*, *Philodendron oligospermum*, *Philodendron rugosum*, *Philonotis andina*, *Pilea gallowayana*, *Pinguicula elongata*, *Piper laguna-cochanum*, *Piper sodiroi*, *Piper subflavum*, *Pipreola jucunda*, *Pitcairnia commixta*, *Pitcairnia cosangaensis*, *Pitcairnia fusca*, *Pittosporum undulatum*, *Plagiocheilus frigidus*, *Plagiocheilus solivaeformis*, *Pleurothallis ensata*, *Pleurothallis macra*, *Pleurothallis truncata*, *Plutarchia guascensis*, *Poa cucullata*, *Poa paramoensis*, *Poa pauciflora*, *Polylepis lanuginosa*, *Polylepis quadrijugata*, *Polylepis reticulata*, *Polypodium mindense*, *Polypodium monosorum*, *Polypodium segregatum*, *Polytrichadelphus ciliatus*, *Pouteria capacifolia*, *Prunus antioquiensis*, *Prunus herthae*, *Psammisia debilis*, *Psammisia occidentalis*, *Psammisia sclerantha*, *Psychotria boqueronensis*, *Psychotria cuatrecasii*, *Puya glomerifera*, *Puya goudotiana*, *Puya nitida*, *Puya santosii*, *Puya trianae*, *Pyrrhura hoematotis*, *Racinaea subalata*, *Rallus semiplumbeus*, *Ranunculus nubigenus*, *Renealmia fragilis*, *Renealmia sessilifolia*, *Rhodospatha*

densinervia, Rhodostemonodaphne laxa, Rhynchospora paramora, Ribes hirtum, Ribes lehmannii, Rubus choachiensis, Rubus gachetensis, Ruilopezia atropurpurea, Ruilopezia marcescens, Rumex tolimensis, Saguinus leucopus, Salvia pichinchensis, Saurauia chiliantha, Saurauia crassiseppala, Saurauia omichlophila, Saurauia peduncularis, Saurauia pseudostrigillosa, Schefflera acaropunctata, Schefflera lasiogyne, Schefflera marginata, Schefflera ramosissima, Scorpidium scorpioides, Scytalopus griseicollis, Scytalopus rodriguezi, Scytalopus vicinior, Senecio culcitoides, Senecio formosoides, Senecio hypsobates, Senecio leucanthemoides, Senecio madagascariensis, Senecio niveoaurus, Senecio subbrunclnatus, Setaria cernua, Siparuna croatii, Siparuna palenquensis, Siphocampylus affinis, Siphocampylus brevicalyx, Siphocampylus columnae, Solanum crinitipes, Solanum paucijugum, Sorocea sarcocarpa, Sparrmannia africana, Sphaeradenia hamata, Sphaeradenia horrida, Sphagnum compactum, Sphagnum oxyphyllum, Sphyrospermum boekei, Sphyrospermum grandifolium, Sporobolus bogotensis, Stachys bogotensis, Stachys elliptica, Stelis columnaris, Stelis piperina, Stellaria recurvata, Stenospermation longifolium, Stilpnophyllum grandifolium, Stilpnophyllum oellgaardii, Stipa milleana, Stipa rosea, Symphyogyna bogotensis, Symplocos cundinamarcensis, Symplocos rhomboidea, Symplocos theiformis, Synallaxis castanea, Synallaxis subpudica, Syntrichia andicola, Tagetes zypaquirensis, Tangara rufigenis, Telipogon nervosus, Ternstroemia cleistogama, Terpsichore heteromorpha, Terpsichore pichinchae, Tetragastris varians, Thelypteris rigescens, Themistoclesia epiphytica, Theobroma gileri, Thibaudia andrei, Thibaudia grantii, Thibaudia parvifolia, Thomasomys hylophilus, Thomasomys niveipes, Thryophilus nicefori, Tibouchina gleasoniana, Tibouchina paleacea, Tibouchina pendula, Tillandsia emergens, Tillandsia incarnata, Tillandsia lajensis, Tillandsia secunda, Tillandsia superba, Tillandsia truncata, Tournefortia ramosissima, Uncinia paludosa, Uniola condensata, Urothraupis stolzmanni, Urtica longispica, Valeriana adscendens, Valeriana arborea, Valeriana bracteata, Valeriana tatamana, Valeriana tomentosa, Verbesina brachypoda, Verbesina latisquama, Verbesina lloensis, Verbesina sodiroi, Viburnum anabaptista, Viburnum antioquiense, Vigna venusta, Viola glandularis, Vireo masteri, Weinmannia polyphylla, Wettinia anomala, Xenophyllum crassum, Zanthoxylum lepidopterophilum, Zygodon pichinchensis

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