

Using empirical and simulated data to study the influence of
environmental heterogeneity on fish species richness in two
biogeographic provinces

Supporting Information

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Appendix S1 Summary of fish species sampled in the two biogeographic provinces.

Table 1: Summary of fish species sampled in the two biogeographic provinces.

<i>Order</i>	<i>Family</i>	<i>Genus</i>	<i>Species</i>	Mean abundance (catch per unit effort)	Mean fork length (cm)		
<i>Acipenseriformes</i>	<i>Acipenseridae</i>	<i>Acipenser</i>	<i>brevirostrum</i>	3.67	59.90		
			<i>oxyrinchus</i>	2.50	27.81		
<i>Anguilliformes</i>	<i>Polyodontidae</i>	<i>Polyodon</i>	<i>spathula</i>	1.50	14.25		
	<i>Anguillidae</i>	<i>Anguilla</i>	<i>rostrata</i>	1.38	43.64		
	<i>Congridae</i>	<i>Conger</i>	<i>oceanicus</i>	1.00	20.10		
<i>Atheriniformes</i>	<i>Atherinopsidae</i>	<i>Membras</i>	<i>martinica</i>	12.33	6.69		
		<i>Menidia</i>	<i>menidia</i>	2.50	6.72		
<i>Aulopiformes</i>	<i>Synodontidae</i>	<i>Synodus</i>	<i>foetens</i>	1.90	15.92		
<i>Batrachoidiformes</i>	<i>Batrachoididae</i>	<i>Opsanus</i>	<i>beta</i>	2.58	15.30		
			<i>pardus</i>	1.50	16.52		
			<i>tau</i>	4.05	19.29		
			<i>plectrodon</i>	1.20	28.51		
<i>Beloniformes</i>	<i>Belonidae</i>	<i>Porichthys</i>	<i>marina</i>	6.00	20.15		
<i>Carcharhiniformes</i>	<i>Carcharhinidae</i>	<i>Carcharhinus</i>	<i>isodon</i>	1.00	38.00		
			<i>limbatus</i>	1.00	39.20		
			<i>porosus</i>	1.00	50.50		
<i>Clupeiformes</i>	<i>Sphyrnidae</i>	<i>Sphyrna</i>	<i>tiburo</i>	1.00	37.47		
	<i>Triakidae</i>	<i>Mustelus</i>	<i>canis</i>	4.67	53.95		
	<i>Clupeidae</i>	<i>Alosa</i>	<i>aestivalis</i>	3.62	7.95		
			<i>pseudoharengus</i>	6.38	7.35		
			<i>sapidissima</i>	7.33	10.43		
			<i>Brevoortia</i>	<i>gunteri</i>	35.17	7.99	
			<i>patronus</i>	20.81	8.79		
			<i>smithi</i>	1.00	12.20		
			<i>tyrannus</i>	5.69	13.19		
			<i>Clupea</i>	<i>harengus</i>	21.11	10.08	
			<i>Dorosoma</i>	<i>cepedianum</i>	14.26	16.91	
			<i>petenense</i>	11.85	10.37		
			<i>Etrumeus</i>	<i>teres</i>	1.00	20.00	
			<i>Harengula</i>	<i>jaguana</i>	2.47	9.70	
<i>Opisthonema</i>	<i>oglinum</i>	2.22	8.46				
<i>Sardinella</i>	<i>aurita</i>	3.00	13.07				
<i>Engraulidae</i>	<i>Anchoa</i>	<i>hepsetus</i>	8.66	6.81			
		<i>mitschilli</i>	14.00	5.12			
		<i>Cypriniformes</i>	<i>Catostomidae</i>	<i>Carpiodes</i>	<i>cyprinus</i>	12.00	38.84
				<i>Catostomus</i>	<i>commersoni</i>	2.00	22.07
<i>Moxostoma</i>	<i>macrolepidotum</i>			1.00	37.40		
<i>Cyprinidae</i>	<i>Carassius</i>			<i>auratus</i>	2.50	26.49	
	<i>Cyprinus</i>	<i>carpio</i>	2.83	57.31			
	<i>Notemigonus</i>	<i>crysoleucas</i>	2.00	14.00			
	<i>Notropis</i>	<i>atherinoides</i>	10.00	9.71			
<i>Cyprinodontiformes</i>	<i>Fundulidae</i>	<i>Fundulus</i>	<i>hudsonius</i>	2.67	8.17		
			<i>grandis</i>	14.00	9.95		
<i>Elopiformes</i>	<i>Elopidae</i>	<i>Elops</i>	<i>saurus</i>	1.14	21.20		
<i>Gadiformes</i>	<i>Gadidae</i>	<i>Microgadus</i>	<i>tomcod</i>	10.30	9.41		
		<i>Pollachius</i>	<i>virens</i>	1.00	13.10		
		<i>Lotidae</i>	<i>Enchelyopus</i>	<i>cimbrius</i>	1.50	21.48	

	<i>Merlucciidae</i>	<i>Merluccius</i>	<i>bilinearis</i>	2.00	20.98
	<i>Phycidae</i>	<i>Urophycis</i>	<i>chuss</i>	3.67	24.75
			<i>regia</i>	4.62	21.65
			<i>tenuis</i>	3.86	21.56
<i>Gasterosteiformes</i>	<i>Gasterosteidae</i>	<i>Gasterosteus</i>	<i>aculeatus</i>	1.00	7.80
<i>Lampriformes</i>	<i>Trachipteridae</i>	<i>Desmodema</i>	<i>polystictum</i>	1.00	16.95
<i>Lepisosteiformes</i>	<i>Lepisosteidae</i>	<i>Atractosteus</i>	<i>spatula</i>	1.00	48.00
		<i>Lepisosteus</i>	<i>oculatus</i>	1.00	47.00
			<i>osseus</i>	4.00	91.18
<i>Lophiiformes</i>	<i>Ogcocephalidae</i>	<i>Ogcocephalus</i>	<i>radiatus</i>	1.00	19.70
<i>Mugiliformes</i>	<i>Mugilidae</i>	<i>Mugil</i>	<i>cephalus</i>	2.89	17.53
			<i>curema</i>	1.57	12.21
<i>Ophidiiformes</i>	<i>Ophidiidae</i>	<i>Ophidion</i>	<i>marginatum</i>	1.50	16.85
<i>Osmeriformes</i>	<i>Osmeridae</i>	<i>Osmerus</i>	<i>mordax</i>	1.00	12.15
<i>Perciformes</i>	<i>Carangidae</i>	<i>Carangoides</i>	<i>ruber</i>	6.00	6.48
		<i>Caranx</i>	<i>crysos</i>	2.00	15.07
			<i>hippos</i>	3.09	8.92
			<i>latus</i>	2.00	8.91
		<i>Chloroscombrus</i>	<i>chrysurus</i>	25.50	7.31
		<i>Decapterus</i>	<i>punctatus</i>	7.00	13.21
		<i>Hemicaranx</i>	<i>amblyrhynchus</i>	2.67	12.01
		<i>Selar</i>	<i>crumenophthalmus</i>	7.00	9.40
		<i>Selene</i>	<i>setapinnis</i>	1.62	6.00
			<i>vomer</i>	2.14	5.60
		<i>Trachinotus</i>	<i>carolinus</i>	2.00	9.89
			<i>falcatus</i>	4.50	6.98
	<i>Centrarchidae</i>	<i>Lepomis</i>	<i>gibbosus</i>	8.14	11.13
			<i>macrochirus</i>	4.86	14.94
			<i>microlophus</i>	3.00	10.13
		<i>Micropterus</i>	<i>salmoides</i>	1.00	10.50
		<i>Pomoxis</i>	<i>annularis</i>	1.40	15.12
	<i>Centropomidae</i>	<i>Centropomus</i>	<i>undecimalis</i>	1.00	24.00
	<i>Chaetodontidae</i>	<i>Chaetodon</i>	<i>ocellatus</i>	2.00	4.85
	<i>Ephippidae</i>	<i>Chaetodipterus</i>	<i>faber</i>	3.13	7.47
	<i>Gerreidae</i>	<i>Eucinostomus</i>	<i>argenteus</i>	3.20	7.03
			<i>gula</i>	1.40	9.18
			<i>lefroyi</i>	6.50	7.64
	<i>Gobiidae</i>	<i>Gobioides</i>	<i>broussonneti</i>	1.00	19.60
		<i>Gobiosoma</i>	<i>bosc</i>	3.00	3.63
	<i>Haemulidae</i>	<i>Haemulon</i>	<i>plumieri</i>	9.50	8.96
		<i>Orthopristis</i>	<i>chrysoptera</i>	7.60	12.00
	<i>Labridae</i>	<i>Halichoeres</i>	<i>caudalis</i>	1.00	11.50
		<i>Lachnolaimus</i>	<i>maximus</i>	5.00	6.80
		<i>Tautoga</i>	<i>onitis</i>	10.60	17.06
		<i>Tautogolabrus</i>	<i>adpersus</i>	4.11	10.22
	<i>Lutjanidae</i>	<i>Lutjanus</i>	<i>griseus</i>	2.00	10.30
			<i>synagris</i>	2.67	8.16
	<i>Moronidae</i>	<i>Morone</i>	<i>americana</i>	70.75	13.94
			<i>saxatilis</i>	10.09	15.59
	<i>Mullidae</i>	<i>Upeneus</i>	<i>parvus</i>	1.00	8.60
	<i>Percidae</i>	<i>Etheostoma</i>	<i>olmstedii</i>	1.00	2.50
		<i>Perca</i>	<i>flavescens</i>	14.00	17.60
	<i>Pholidae</i>	<i>Pholis</i>	<i>gunnellus</i>	2.00	10.80
	<i>Polynemidae</i>	<i>Polydactylus</i>	<i>octonemus</i>	1.91	11.45
	<i>Pomatomidae</i>	<i>Pomatomus</i>	<i>saltatrix</i>	2.21	16.78
	<i>Priacanthidae</i>	<i>Priacanthus</i>	<i>arenatus</i>	1.00	10.60
	<i>Rachycentridae</i>	<i>Rachycentron</i>	<i>canadum</i>	2.00	21.03
	<i>Scaridae</i>	<i>Sparisoma</i>	<i>radians</i>	4.00	12.63

	<i>Sciaenidae</i>	<i>Aplodinotus</i>	<i>grunniens</i>	4.00	14.85
		<i>Bairdiella</i>	<i>chrysoura</i>	6.09	12.56
			<i>sanctaeluciaae</i>	19.00	14.84
		<i>Cynoscion</i>	<i>arenarius</i>	12.43	11.20
			<i>nebulosus</i>	1.25	16.36
			<i>nothus</i>	1.83	12.23
			<i>regalis</i>	25.94	15.04
		<i>Leiostomus</i>	<i>xanthurus</i>	33.85	12.52
		<i>Menticirrhus</i>	<i>americanus</i>	1.25	20.14
			<i>saxatilis</i>	1.67	16.38
		<i>Micropogonias</i>	<i>undulatus</i>	21.83	14.04
		<i>Odontoscion</i>	<i>dentex</i>	1.00	15.80
		<i>Pogonias</i>	<i>cromis</i>	3.38	22.58
		<i>Sciaenops</i>	<i>ocellatus</i>	3.75	28.81
		<i>Stellifer</i>	<i>lanceolatus</i>	1.00	11.80
	<i>Scombridae</i>	<i>Scomberomorus</i>	<i>cavalla</i>	1.50	13.66
			<i>maculatus</i>	2.60	14.80
	<i>Serranidae</i>	<i>Centropristis</i>	<i>philadelphica</i>	2.00	12.71
			<i>striata</i>	3.43	14.22
		<i>Diplectrum</i>	<i>formosum</i>	1.00	12.57
		<i>Mycteroperca</i>	<i>bonaci</i>	1.00	14.50
			<i>microlepis</i>	1.00	23.20
		<i>Serranus</i>	<i>subligarius</i>	2.00	8.60
	<i>Sparidae</i>	<i>Archosargus</i>	<i>probaticeps</i>	1.27	23.35
		<i>Calamus</i>	<i>arctifrons</i>	2.67	12.54
			<i>leucosteus</i>	1.00	17.00
		<i>Diplodus</i>	<i>holbrooki</i>	6.09	8.57
		<i>Lagodon</i>	<i>rhomboides</i>	20.05	10.12
		<i>Stenotomus</i>	<i>caprinus</i>	2.00	9.00
			<i>chrysops</i>	40.67	11.32
	<i>Sphyraenidae</i>	<i>Sphyraena</i>	<i>borealis</i>	4.00	10.40
	<i>Stromateidae</i>	<i>Peprilus</i>	<i>alepidotus</i>	5.65	6.31
			<i>burti</i>	3.00	7.16
			<i>triacanthus</i>	21.51	8.27
	<i>Trichiuridae</i>	<i>Trichiurus</i>	<i>lepturus</i>	2.06	32.90
	<i>Uranoscopidae</i>	<i>Astroscopus</i>	<i>guttatus</i>	1.00	14.15
<i>Pleuronectiformes</i>	<i>Achiridae</i>	<i>Achirus</i>	<i>lineatus</i>	2.00	8.65
		<i>Gymnachirus</i>	<i>texae</i>	1.00	7.50
		<i>Trinectes</i>	<i>maculatus</i>	17.44	9.93
	<i>Cynoglossidae</i>	<i>Symphurus</i>	<i>civitatium</i>	1.00	12.40
			<i>plagiusa</i>	6.41	13.61
	<i>Paralichthyidae</i>	<i>Ancylosetta</i>	<i>ommata</i>	1.00	18.40
		<i>Citharichthys</i>	<i>macrops</i>	2.00	11.25
			<i>spilopterus</i>	2.71	8.48
		<i>Etropus</i>	<i>crossotus</i>	3.00	12.50
			<i>microstomus</i>	2.40	10.63
			<i>sp</i>	1.00	10.20
		<i>Hippoglossina</i>	<i>oblonga</i>	6.20	22.52
		<i>Paralichthys</i>	<i>albigutta</i>	1.67	25.47
			<i>dentatus</i>	3.15	26.34
			<i>lethostigma</i>	2.02	17.51
		<i>Syacium</i>	<i>gunteri</i>	1.00	10.20
	<i>Pleuronectidae</i>	<i>Pseudopleuronectes</i>	<i>americanus</i>	10.04	15.94
	<i>Scophthalmidae</i>	<i>Scophthalmus</i>	<i>aquosus</i>	6.29	15.69
<i>Rajiformes</i>	<i>Dasyatidae</i>	<i>Dasyatis</i>	<i>americana</i>	7.50	37.39
			<i>centoura</i>	1.00	77.00
			<i>sabina</i>	3.53	25.37
			<i>say</i>	2.00	42.58

	<i>Gymnuridae</i>	<i>Gymnura</i>	<i>altavela</i>	1.00	47.50
			<i>micrura</i>	2.50	51.50
	<i>Myliobatidae</i>	<i>Myliobatis</i>	<i>freminvillei</i>	1.33	45.33
		<i>Rhinoptera</i>	<i>bonasus</i>	1.33	35.75
	<i>Rajidae</i>	<i>Leucoraja</i>	<i>erinacea</i>	5.45	40.62
			<i>ocellata</i>	1.50	36.27
		<i>Raja</i>	<i>eglanteria</i>	3.25	54.74
<i>Scorpaeniformes</i>	<i>Cottidae</i>	<i>Myoxocephalus</i>	<i>aenaeus</i>	32.50	10.37
			<i>octodecemspinosus</i>	1.00	14.05
	<i>Triglidae</i>	<i>Prionotus</i>	<i>alatus</i>	1.00	11.95
			<i>carolinus</i>	5.27	13.23
			<i>evolans</i>	2.22	13.70
			<i>roseus</i>	4.00	10.95
			<i>rubio</i>	1.00	12.40
			<i>tribulus</i>	2.12	8.87
<i>Siluriformes</i>	<i>Ariidae</i>	<i>Ariopsis</i>	<i>felis</i>	7.43	19.21
		<i>Bagre</i>	<i>marinus</i>	15.79	11.22
	<i>Ictaluridae</i>	<i>Ameiurus</i>	<i>catus</i>	8.92	19.92
			<i>natalis</i>	5.00	22.44
			<i>nebulosus</i>	10.00	20.76
		<i>Ictalurus</i>	<i>furcatus</i>	45.82	17.56
			<i>punctatus</i>	15.46	21.34
<i>Syngnathiformes</i>	<i>Syngnathidae</i>	<i>Hippocampus</i>	<i>erectus</i>	1.17	11.20
		<i>Syngnathus</i>	<i>floridae</i>	1.00	16.50
			<i>fuscus</i>	1.00	20.80
			<i>louisianae</i>	3.67	13.36
			<i>scovelli</i>	1.00	20.00
<i>Tetraodontiformes</i>	<i>Diodontidae</i>	<i>Chilomycterus</i>	<i>reticulatus</i>	5.25	12.03
			<i>schoepfi</i>	1.80	16.05
		<i>Diodon</i>	<i>hystrix</i>	2.00	16.40
	<i>Monacanthidae</i>	<i>Aluterus</i>	<i>schoepfi</i>	1.00	16.03
			<i>scriptus</i>	3.33	17.26
		<i>Stephanolepis</i>	<i>hispidus</i>	4.75	9.91
			<i>setifer</i>	4.00	6.05
	<i>Ostraciidae</i>	<i>Acanthostracion</i>	<i>quadricornis</i>	1.56	15.02
	<i>Tetraodontidae</i>	<i>Canthigaster</i>	<i>rostrata</i>	1.00	8.00
		<i>Lagocephalus</i>	<i>laevigatus</i>	1.00	18.20
		<i>Sphoeroides</i>	<i>maculatus</i>	2.24	12.69
			<i>nephelus</i>	16.00	3.89
			<i>parvus</i>	4.13	6.29

Appendix S2 Simulation details and parametrization.

Spatio-temporal Moran's I decomposition

The Moran's I_{global} statistic (equation 1) was computed by pooling all observations in each biogeographic provinces. To ensure that the measured local I_{global} reflected the spatial heterogeneity of environmental conditions rather than the temporal variability of environmental conditions, we decomposed I_{global} (equation 1) into its spatial and temporal components using equation 2.

$$I_{global} = (n - 1) \frac{x_i - \bar{X}}{\sum_{i=1}^n (x_i - \bar{X})^2} \sum_{j=1}^n w_{ij} (x_j - \bar{X}) \quad (1)$$

$$I_{temporal} = I_{global} - I_{spatial} \quad (2)$$

Where $I_{temporal}$, I_{global} and $I_{spatial}$ are respectively the *temporal*, *spatio-temporal* and *spatial* Moran's I . I_{global} has been computed on data pooled at the biogeographic provinces level whereas $I_{spatial}$ has been computed at each year in each biogeographic province. The results of the decomposition are presented in figure 1.

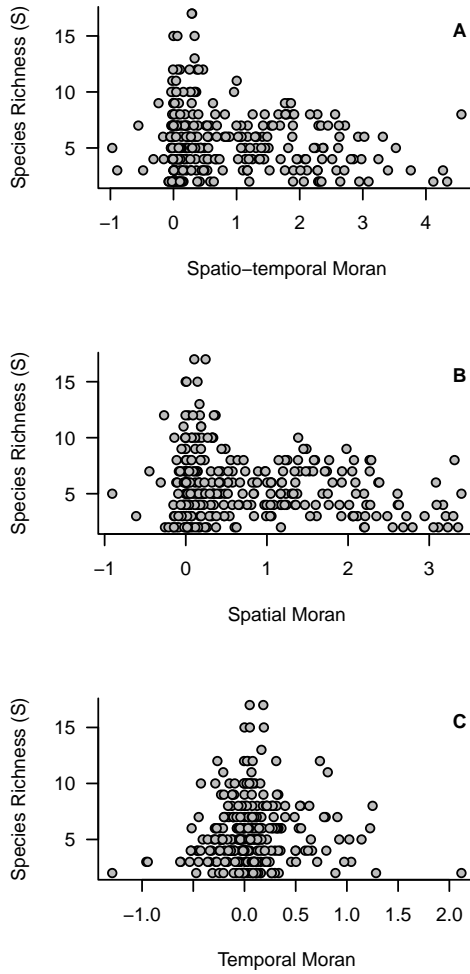


Figure 1: Results of the Moran's I decomposition. (A) Spatio-temporal data (used in this study), (B) Spatial Moran's I and (C) Temporal Moran's I .

Distribution ranges

To determine the spatial distribution range of each species (ellipse size), we used a long-tail distribution yielding small ranges for most species and large ranges for few species (Figure 2). The minimum and maximum distribution range thresholds were based on the observed regional distribution of species ($r_{min} \leq r \leq r_{max}$ with $r_{min} = 10$ km and $r_{max} = 1000$ km).

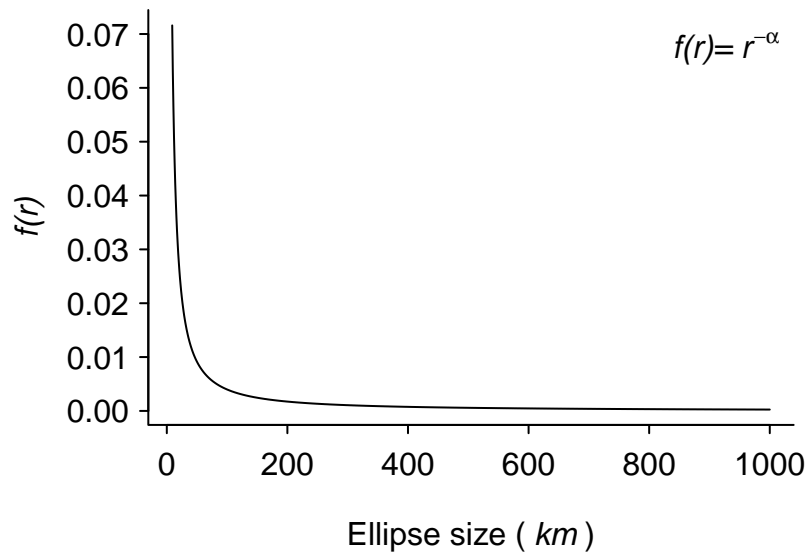


Figure 2: Power function used to randomly pick the distribution range r for species placed on the surface grid.

Examples of the regional distribution for four species found in the Louisianian biogeographic province.

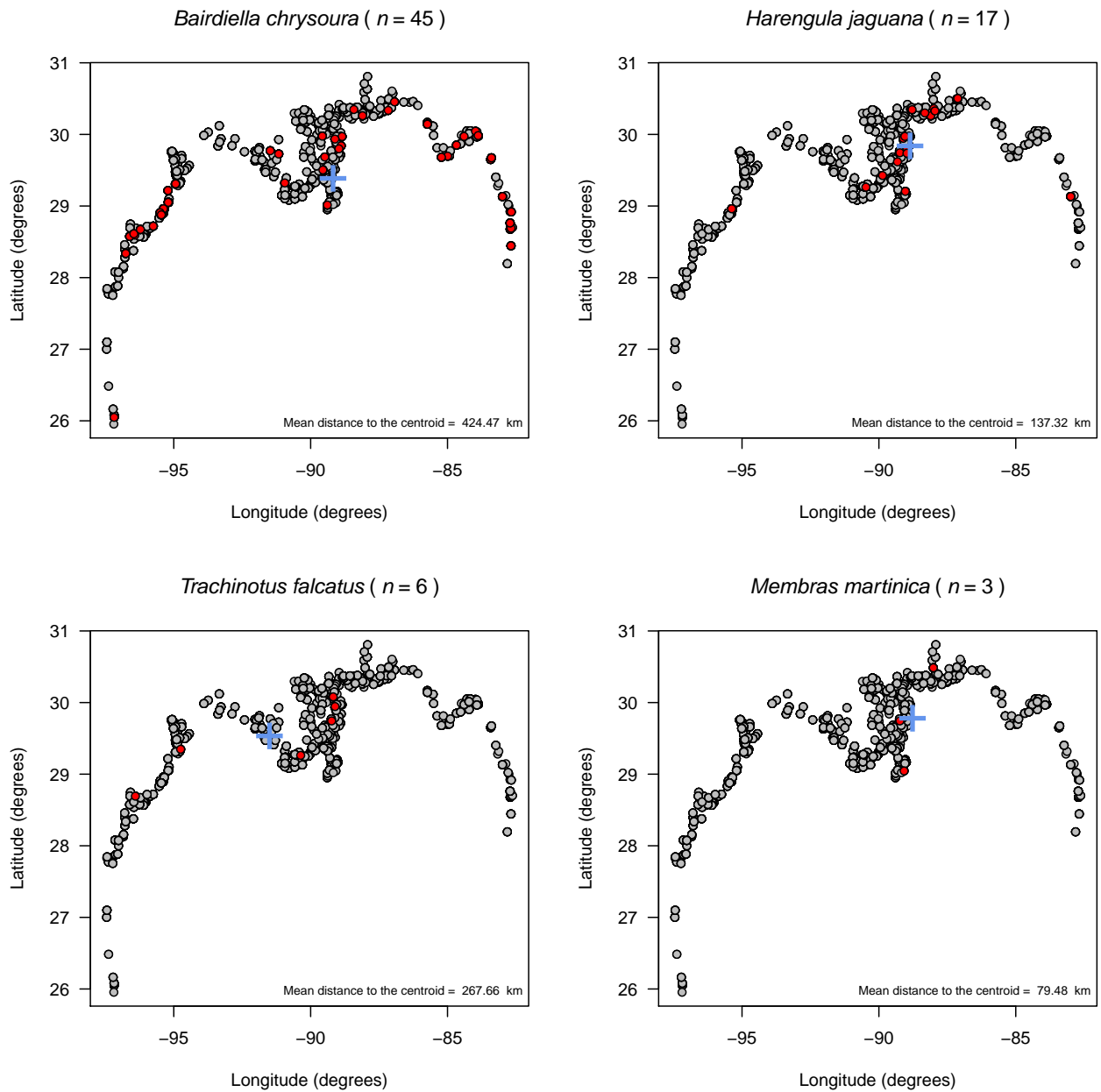


Figure 3: Examples of the regional distribution for four species found in the Louisianian biogeographic province. The red dots show the locations where each species was found whereas the blue crosses are the centroids of these locations. The average distances to centroids for species found in Louisianian and Virginian biogeographic provinces are 134.4 km and 85.1 km respectively.

Example of connectivity graph used to identify neighbours of region points by Euclidean distance.

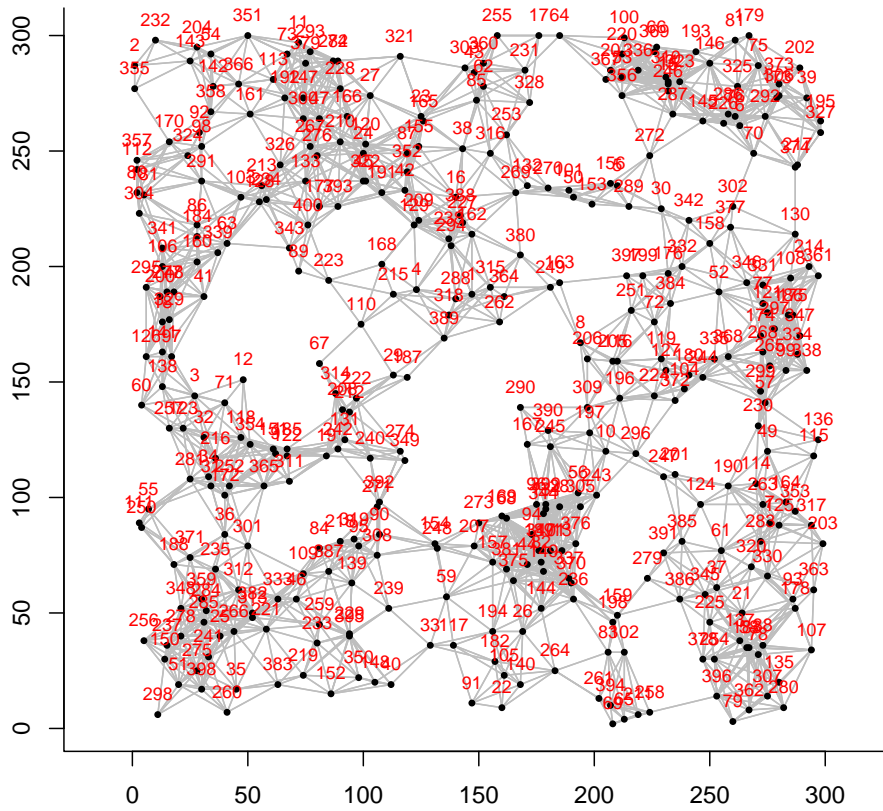


Figure 4: Connectivity graph identifying neighbours of region points falling under the 10% maximum range (see Methods for detailed information).