

# Contents

*Preface*

*page ix*

<b>1</b>	<b>Ecological Processes and Network Systems</b>	<b>1</b>
1.1	Introduction	1
1.2	Network Analysis in Ecology	1
1.3	Classification of Network Questions	10
1.3.1	Criterion 1: Structure-and-Function	10
1.3.2	Criterion 2: Interactions	11
1.3.3	Criterion 3: Dimensions of Space and Time	11
1.3.4	Criterion 4: Multilayer	13
1.4	Concluding Comments: Questions and Answers	13
<b>2</b>	<b>Structural Properties of Networks</b>	<b>18</b>
2.1	Introduction	18
2.2	Properties of Nodes and Edges	19
2.2.1	Degree and Degree Distribution	19
2.2.2	Local Density	22
2.2.3	Connectivity	23
2.2.4	Centrality	24
2.2.5	Partitions and Clusters	24
2.2.6	Assortativity	26
2.2.7	Subgraphs, Motifs, and Graphlets	27
2.3	Methods of Network Analysis	30
2.3.1	Partitioning	30
2.3.2	Spectral Graph Theory	31
2.3.2.1	Spectral Graph Theory and Ecological Applications	36
2.3.2.2	Spectral Graph Theory: Why Does It Work?	37
2.3.3	Analysis of Signed Networks	38
2.3.4	Information and Entropy	43
2.3.4.1	Graphlet Information Measures	46
2.3.4.2	Search Information and Related Entropies	47
2.3.4.3	Information Theory and Ecological Applications	49

2.4	Properties Evaluated	50
2.4.1	Complexity	50
2.4.2	Modularity	53
2.4.3	Keystoneness	55
2.4.4	Hierarchies	55
2.4.5	Interdependence and Choice of Properties and Measures	58
2.5	Comparing Networks	59
2.5.1	Probability Calculations	59
2.5.2	Graphlets	60
2.5.3	Kernel Function Methods	61
2.5.3.1	“Kernel” versus “Kernel”	61
2.5.4	Spectral Methods	65
2.5.5	Dissimilarity	66
2.6	Concluding Comments	67
<b>3</b>	<b>Quantitative Analysis of Dynamic Networks</b>	<b>69</b>
3.1	Introduction	69
3.2	Inference	72
3.2.1	Sampling Networks	72
3.2.2	Incomplete Data	77
3.2.3	Network Inference	78
3.2.3.1	Estimation	78
3.2.3.2	Significance and Randomisation	79
3.3	Statistical Considerations	79
3.3.1	Statistics and Ecological Networks	79
3.3.2	Correlation Networks	80
3.3.3	Methodological Comment	83
3.4	Structure and Function in Dynamic Networks	84
3.4.1	Dynamic Networks: Concepts and Attributes	84
3.4.2	Stability, Resilience, Robustness, and so on	84
3.4.3	Relating Structure and Function Using Graphlets	88
3.4.3.1	Basic Graphlets (No Directions or Signs on Edges)	89
3.4.3.2	Directed Graphlets	93
3.4.3.3	Signed Graphlets	95
3.4.3.4	Other Extensions of Graphlet Analysis	97
3.4.3.5	Comment on Network Sampling and Graphlets	101
3.4.4	Analysis of Network Flow	101
3.5	Causal Networks	105
3.6	Concluding Comments	119
<b>4</b>	<b>Multilayer, -type, and -level Networks</b>	<b>121</b>
4.1	Introduction	121
4.2	Multilayer Networks	123
4.2.1	Node Degrees in Multilayer Networks	128

4.2.2	Walks and Paths	128
4.2.3	Centrality and Node Ranking	129
4.2.3.1	Eigenvector Versatility	131
4.2.4	Clusters and Clustering	132
4.2.5	Spectral Properties	134
4.2.6	Resilience, Robustness, and Fragility	135
4.2.7	Comments on Multilayer Networks	137
4.3	Beyond Multilayer	137
4.4	Multitype Nodes	138
4.4.1	Phenology Networks	140
4.5	Multiple Interactions and Multiorder Interactions	145
4.5.1	Multinode Edges	146
4.5.2	Multistem Structures	148
4.6	Multilevel Networks	155
4.7	Multiscale Networks	157
4.8	Generalising Motifs (Multinode Motifs) and Graphlets	158
4.9	Concluding Comments	162
<b>5</b>	<b>Tying It All Together: Summary and Synthesis</b>	<b>164</b>
5.1	Network Thinking	164
5.1.1	Structure and Function	164
5.1.2	Ecological Interactions	165
5.1.3	Space and Time	167
5.1.4	Multilayer	167
5.2	Networks: Construction and Reconstruction	168
5.3	Network Complexity and Inference	169
5.4	Dynamics <i>on</i> and <i>of</i> Ecological Networks	169
5.5	A Conceptual Atlas of Network Concepts, Structures, and Methods	170
5.5.1	It All Ties Together	170
5.6	Concluding Comments	174
	<i>Glossary</i>	176
	<i>References</i>	201
	<i>Index</i>	219

*Colour plates can be found between pages 118 and 119.*