Graphical modeling of seabird distributions

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Summary. Graphical modeling of seabird distributions. Simultaneous estimation of conditional spatial interrelation for a subset of 79 seabird species by means of a spatial dependence graph model (SDGM). Linkage to Social network analysis toolbox to detect the most influential species (in term of importance within the estimated SDGM)

Keywords: Graphical modeling, Species importance, Marked point process, Network centrality measures, Seabird distribution

1. Introduction

The occurrence of a sea bird species in a particular location is affected (either positively or negatively) by the occurrence of other species in the same location. Thus, external factors that may cause changes to the distribution of a single species will undoubtedly have an effect on the distribution of other species. Determining these associations between different species has been difficult (CITATIONS), especially when trying to associate many species all at once.

Quantifying the spatial dependence structure between bird species and environmental covariates is important. While studies have related the spatial distribution of one species with that of a prey or predator species, or of environmental variables acting as proxies for climate (Goyert et al. 2014, 2016), there has been relatively few studies that investigate and utilize measures of inter-species dependence.

Community models may combine several species, known to have facilitative interactions with each other, into one model (Goyert et al. 2016; Sollmann et al. 2016). However, these models treat the observed data the same way as if the observations are of only one species.

Studying the degree of interaction between species may help inform ocean planning. Mapping the distribution of rare and endangered avian species is important when planning the placement of offshore wind farms. Such rare species are obviously difficult to monitor, so finding a more commonly occuring species that is highly dependent with the rare species has ecological importance.

Attempts at modeling between-species interactions are often limited to the bivariate case (Andersen 1992; Nightingale et al. 2015). For three or more species, models are usually hindered by computing time due to the estimation of very many interaction parameters (Jalilian et al. 2015).

Ecological data usually contains spatial observations from multiple species of interest.

There is a need for fast and practically applicable methods for analysing multivariate point patterns, and is currently a growing but challenging topic for researchers (Møller and Waagepetersen 2016).

Information on the distribution of sea birds, especially in the form of maps, is of particular interest to ecologists, environmentalists and policymakers. Maps conveying the spatial and temporal distribution over the US Mid- and Northeast-Atlantic ocean regions were created by Balderama et al. (2016) for several individual species of marine birds.

Models are usually run on inidivudal species. There is a danger in this in that tt is generally known that species distributions are not independent. Maps of the spatial distribution of marine birds undoubetedly have some overlap

However, a multivariate analysis of sea bird distribution would be very useful in determining how bird species affect one another's presence.

This will also help us to categorize observations of unidentified or unknown species to those of identified species.

There are several advantages with this approach:

1. These observations are usually removed before analyzing data at the species level.

Here we include these locations of unknown species and from the results may be able to determine what species they are more likely to be from the resulting network map.

2. Data

Data are point locations of marine bird sightings over the Northeast- and Mid-Atlantic coast regions of the United States, as described in Balderama et al. (2016). The point locations are the longitude and latitude coordinates of the midpoints of line transect segments from boat and aerial surveys between July, 1998 and April, 2014. Species are labelled by its common name and a four-letter species code. Names that include the word "unidentified" accommodate birds identified to a family but not to a species.

Table 1 shows a summary of the observed data by species code and common name. There are 79 different codes. However, some codes signify an unidentified or partially identified species.

Table 1: Summary of observed data by species code.

Species code	**Common name**	**sightings**	**average mark**			
ABDU	American Black Duck	47	1.25			
ARTE	Arctic Tern	103	0.94			
ATPU	Atlantic Puffin	403	1.17			
AUSH	Audubon's Shearwater	86	1.20			
BRSP	Band-rumped Storm-petrel	23	0.29			
BARS	Barn Swallow	99	0.34			
BCPE	Black-capped Petrel	3	1.56			
BLKI	Black-legged Kittiwake	971	1.45			
BLGU	Black Guillemot	75	0.42			
BLSC	Black Scoter	669	4.31			
BOGU	Bonaparte's Gull	708	0.99			
BRPE	Brown Pelican	92	0.29			
BUFF	Bufflehead	159	1.86			
COEI	Common Eider	528	59.74			
COGO	Common Goldeneye	82	1.25			
COLO	Common Loon	1900	0.51			
COMU	Common Murre	153	0.88			
COTE	Common Tern	982	1.80			
COSH	Cory's Shearwater	1138	2.69			
DASC	Dark Scoter (Black or Surf)	199	2.09			
DCCO	Double-crested Cormorant	354	2.37			
DOVE	Dovekie	962	5.73			
FOTE	Forster's Tern	119	0.52			
GBBG	Great Black-backed Gull	3319	2.46			
UBBG	Great or Lesser Black-backed Gull	299	0.18			
GRSH	Great Shearwater	3732	8.99			
GRSK	Great Skua	117	0.61			
HERG	Herring Gull	3978	2.71			
HOGR	Horned Grebe	65	0.07			
LAGU	Laughing Gull	856	0.80			
LESP	Leach's Storm-petrel	1005	3.63			
LETE	Least Tern	61	0.27			
LBBG	Lesser Black-backed Gull	97	0.30			
LTDU	Long-tailed Duck	851	8.64			
MASH	Manx Shearwater	374	0.92			

NOFU	Northern Fulmar	1688	5.25			
NOGA	Northern Gannet	3451	2.51			
PAJA	Parasitic Jaeger	154	0.37			
POJA	Pomarine Jaeger	287	0.70			
RAZO	Razorbill	908	1.26			
REPH	Red Phalarope	394	8.64			
RBME	Red-breasted Merganser	220	0.78			
RNGR	Red-necked Grebe	49	0.11			
RNPH	Red-necked Phalarope	207	7.65			
RTLO	Red-throated Loon	1400	0.59			
RBGU	Ring-billed Gull	530	0.71			
ROST	Roseate Tern	115	0.88			
ROYT	Royal Tern	207	0.22			
SOSH	Sooty Shearwater	871	6.69			
SPSK	South Polar Skua	169	0.74			
SUSC	Surf Scoter	678	4.96			
TBMU	Thick-billed Murre	83	1.33			
UNAL	Unidentified Alcid	555	0.71			
UNBI	Unidentified Bird	543	1.06			
UNCO	Unidentified Cormorant	99	0.43			
UNDD	Unidentified Diving/Sea Duck	121	0.80			
UNGO	Unidentified Goldeneye	34	2.29			
UNGR	Unidentified Grebe	63	0.06			
UNGU	Unidentified Gull	984	2.98			
UNJA	Unidentified Jaeger	78	0.46			
UNLA	Unidentified Large Alcid (Razorbill or Murre)	330	0.84			
UNLG	Unidentified Large Gull	553	3.51			
UNLT	Unidentified Large Tern	91	0.35			
UNLO	Unidentified Loon	754	0.64			
UNME	Unidentified Merganser	117	0.97			
UNMU	Unidentified Murre	73	1.98			
UNPA	Unidentified Passerine	97	0.47			
UNPH	Unidentified Phalarope	292	28.47			
SCAU	Unidentified Scaup	52	11.02			
UNSC	Unidentified Scoter	703	26.64			
UNSH	Unidentified Shearwater	364	3.80			
SHOR	Unidentified Shorebird	87	1.96			
UNSK	Unidentified Skua	89	0.67			
UNSG	Unidentified Small Gull	313	0.38			
UNST	Unidentified Small Tern	184	0.18			
UNSP	Unidentified Storm-petrel	379	40.11			
UNTE	Unidentified Tern	619	2.62			
WWSC	White-winged Scoter	522	2.78			

WISP	Wilson's Storm-petrel	2746	6.88			

While some marine bird species such as various types of gulls have been sighted at numerous locations, other species occurred only very rarely. At the same time, as we defined a minimum of at least 50 marine birds per species as inclusion criteria, this limited number of locations equivalently implies that certain marine bird species appeared in groupings rather than as isolated birds or occurred only in a geographically strictly-limited habitat. An example of such only rarely observed species are black-capped petrels whose 50 counted sighting have only been recorded at $n = 3$ different locations. This reflects our expectations, as black-capped petrels have been classified as endangered species by the IUCN Red List of Threatened Species. Discovering the relevant subset of species whose spatial occurrence is linked to the spatial pattern of any endangered species by means of a SDGM might provide new insights into multivariate interdependencies. This new insights might provide important knowledge for the conservation of endangered species and might assist to understand such phenomena from a global perspective on different natural environments.

3. Methods

- We estimate the conditional spatial dependence structure between different seabird species
- that is, structural dependence between two patterns conditional on all remaining patterns
- so not interrelation between points i and j, but interrelations between components i and j where i and j are sets of points within a bounded planar region.

- edges express the partial (pairwise) interrelation between two species conditional on al remaining species

- we omit to implement a formal test statistic as we assume that dependence might vary between species

- we set a threshold indicating weak/ intermediate partial effects

- we combine spatial dependence graph model with importance tools of social network analysis

- info can provide important insides for species conservation

- eg which are the most important species in the overall graph

Primary idea by Eckardt (2016a), extension to multivariate spp with quantitative marks by Eckardt and Mateu (2016)

Analysis was carried out using the `sdgm` R package of Eckardt (2016b).

4. Results

⋆ in general: important for species conservation: e.g. black-capped petrels only linked to unidentified goldeneyes, both listed as threatened species by IUCN.

⋆ most important species by means of the degree centrality are unidentified alcids, Arctic terns, barn swallows, red phalaropes, dovekies, buffleheads, brown pelicans, unidentified mergansers and great black-backed gulls.

⋆ these species are most often linked to alternative species (no. adjacent species)

⋆ buffleheads, royal terns, unidentified alcids, Arctic terns, common murres, barn swallows, greater shearwaters, manx shearwaters, Bonaparte's gulls and Northern gannets are the most important species by means of the betweenness centrality.

⋆ these species are most often intermediate species, that is most links from a to b path through these species

5. Discussion

Methods for studying multivariate species distributions are still not well developed. Future research may focus on niche partitioning and finding common areas of species overlap.

Identifying ecologically important areas for community assemblages is important in marine spatial planning (Ehler and Douvere 2009), and our study suggests that a diverse set of species may attract (or repel) each other to (or from) feeding areas. We recommend a synthesis of community and ecosystem approaches in applied conservation management, since facilitation and competition fundamentally shape dynamic environmental processes.

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