The Southern Ocean Food Web

Load required libraries:

```
require(igraph)
require(NetIndices)
require(reshape2)
require(ggplot2)
require(devtools)
require(vegan)
```

Source code for functions to describe web properties

```
url <- "https://raw.github.com/jjborrelli/Ecological-Networks/master/Food%20Webs/Rscripts/we
source_url(url)
```

Load in the data

```
# s.ocean <- read.csv('http://esapubs.org/archive/ecol/E092/097/diet.csv')
s.ocean <- read.csv("~/Downloads/diet.csv")
```

Whole Southern Ocean

```
el.df <- data.frame(pred = s.ocean$PREDATOR_NAME, prey = s.ocean$PREY_NAME)

SOgraph <- graph.edgelist(unique(as.matrix(el.df[, 1:2])))

SOadjacency <- get.adjacency(SOgraph, sparse = F)
```

First take a quick look at what the food web looks like. Here I plot the web by trophic level by setting the layout (code shown below). Nodes are plotted with trophic position along the y-axis and plotted along the x-axis according to a random uniform distribution (`runif(x, 0, 1)`).

```
par(mar = c(0, 0, 0, 0))
layouts <- matrix(c(runif(gind$N), tind$TL), ncol = 2)
plot.igraph(SOgraph, layout = layouts, vertex.label = NA, edge.arrow.size = 0.5,
    vertex.size = 1)
```

The plot of the web is not very helpful because there are so many species and far too many interactions. So looking at some of the whole web statistical properties and node properties may be more useful than just plotting the web.

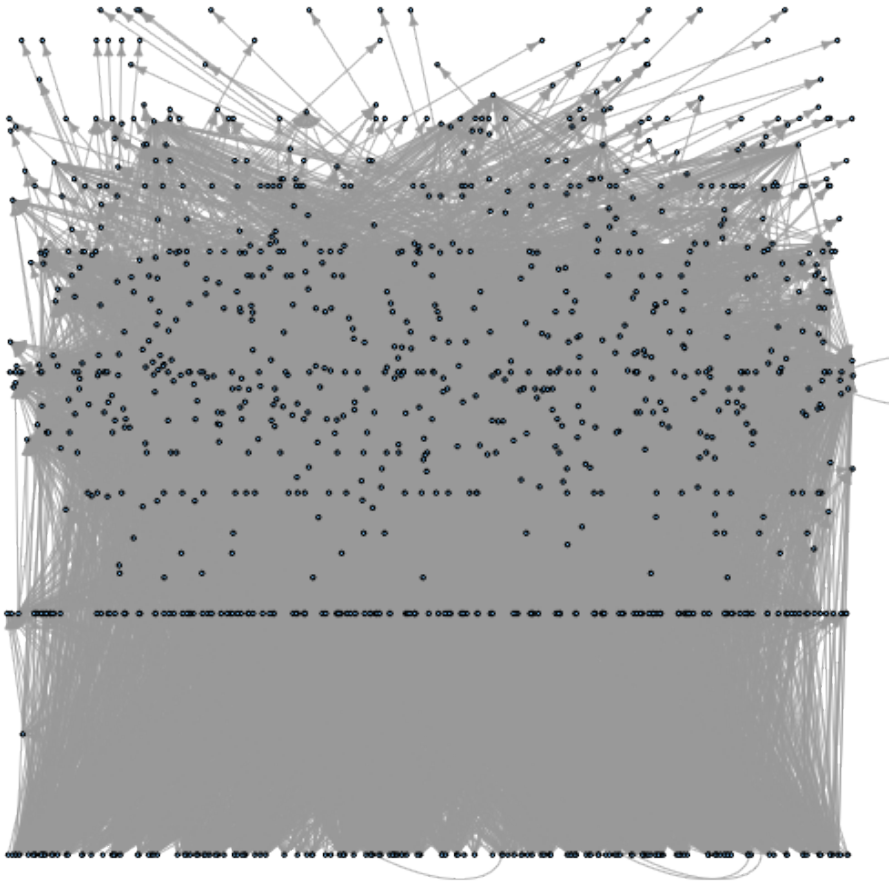


Figure 1: The Southern Ocean food web

The `NetIndices` and `igraph` packages have functions to calculate a number of commonly used food web indices. The function `GenInd` from the `NetIndices` library easily calculates the number of nodes (N), total number of links (L), link density ($\frac{L}{N} = LD$), and connectance (along with some other indices that are not relevant to this dataset). Connectance in this case is calculated as:

$$C = \frac{L}{N * (N - 1)}$$

The `diameter` is the single longest path between two nodes. The `average.path.length` is the mean number of links between any two nodes in the web. The clustering coefficient (or `transitivity`) is the probability that the nearest neighbors of a given vertex are themselves connected. A high clustering coefficient is an indication that a network has "small world" properties. The sum of the diagonal elements of the adjacency matrix gives the number of species that are cannibalistic, with links that loop back to themselves.

Species in a food web may be either basal, intermediate, or top. These positions may be determined simply by examining the degree of each node. The number of links pointing towards a node is its in-degree and the number of links pointing away from a node is the out-degree. In-degree is therefore a measure of how many species the node of interest preys upon (generality) while out-degree is the number of predators a given node has (vulnerability). Basal nodes will have an in-degree of 0, and likewise top species will have an out-degree of 0. Once the number of basal and top species are found, the number of intermediate species is simply the remainder.

```
gind <- GenInd(SOadjacency)
diam <- diameter(SOgraph)
avpath <- average.path.length(SOgraph)
cluster <- transitivity(SOgraph)
cannibals <- sum(diag(SOadjacency))

degrees <- degree(SOgraph, mode = "all")
indegrees <- degree(SOgraph, mode = "in")
outdegrees <- degree(SOgraph, mode = "out")

numBas <- length(indegrees[which(indegrees == 0)])
numTop <- length(outdegrees[which(outdegrees == 0)])
basal <- (numBas/gind$N) * 100
top <- (numTop/gind$N) * 100
int <- ((gind$N - (numBas + numTop))/gind$N) * 100

web.props <- data.frame(N = gind$N, L = gind$Ltot, LD = gind$LD, C = gind$C,
    D = diam, AvgPath = avpath, ClCoef = cluster, Can = cannibals, Bas = basal,
    Top = top, Int = int)
```

```
     N     L    LD        C D AvgPath ClCoef Can  Bas   Top   Int
1 1095 10395 9.493 0.008677 6   2.114 0.1941  30 15.8 69.68 14.52
```

There are a total of 1095 species with 10395 interactions among them. The longest chain described in this food web is 6 but the average chain is 2.1144.

The short average path length in the food web is made clearer by looking at the distribution of trophic positions in the Southern Ocean Food Web.

```
qplot(tind$TL, binwidth = 0.25, geom = "histogram", xlab = "Trophic Position",
    ylab = "Frequency")
```

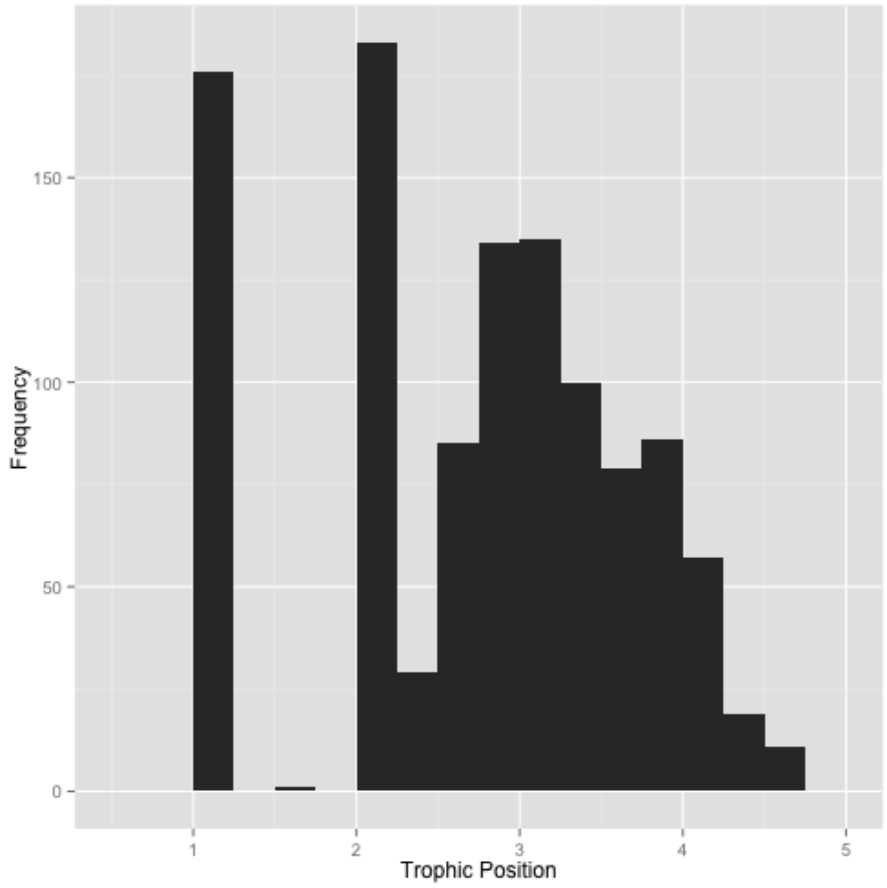


Figure 2: Histogram of trophic positions

There is a tall bar at trophic level 1 and 2 representing plants and herbivores. There is a single organism, *Chionodraco hamatus*, with a trophic level between 1

and 2, suggesting that it consumes both plant and animals (a true omnivore). I am unconvinced, however, that the dataset includes a fully sampled food web and that some of those organisms described as basal are not plants, but are crustaceans, or other small organisms.

Most of the species in the food web are "top" predators with 70% of sampled species having no predators themselves. Plants ("basal species") make up 16% of the web, and the remaining 15% are "intermediate". The disproportionately large proportion of "top" species is unusual compared to other empirically described food webs and may be the result of sampling methods. The connectance of the Southern Ocean Food Web is relatively low at 0.0087, but that is expected with such a large number of species.

The degree distribution of a food web is often described as being power-law distributed, with most nodes having few links, and few nodes having many links. The degree distribution may be plotted as a histogram. Rather than fitting a power law to the distribution I have fit a lognormal distribution to the data, as it appears to be the better fit. In the following plot I have included a line fit to a lognormal (blue) and power law (green) distributions. The lognormal distribution appears to be a better fit to the degree distribution.

```
degdisfit <- fitdistr(degrees, "lognormal")
degdispow <- power.law.fit(degrees, force.continuous = T)

dd <- ggplot(data.frame(degrees = degrees), aes(x = degrees))
dd <- dd + geom_histogram(aes(y = ..density..), binwidth = 5, colour = "black",
    fill = "white")

sequ <- seq(1, 300, 0.25)

dd <- dd + geom_line(aes(x = sequ[1:1095], y = dlnorm(sequ[1:1095], degdisfit[[1]][1],
    degdisfit[[1]][2])), colour = "blue")
dd <- dd + geom_line(aes(x = sequ[1:1095], y = 20 * sequ[1:1095]^-degdispow$alpha,
    colour = "green"))
dd + scale_y_continuous(limits = c(0, 0.12)) + theme(legend.position = "none")
```

By location

The following code splits up the dataframe by the location column. The resulting 228 graph objects get stored in `location.g`. *NOTE: the first location is a blank (" ") indicating that there are some rows without a location*

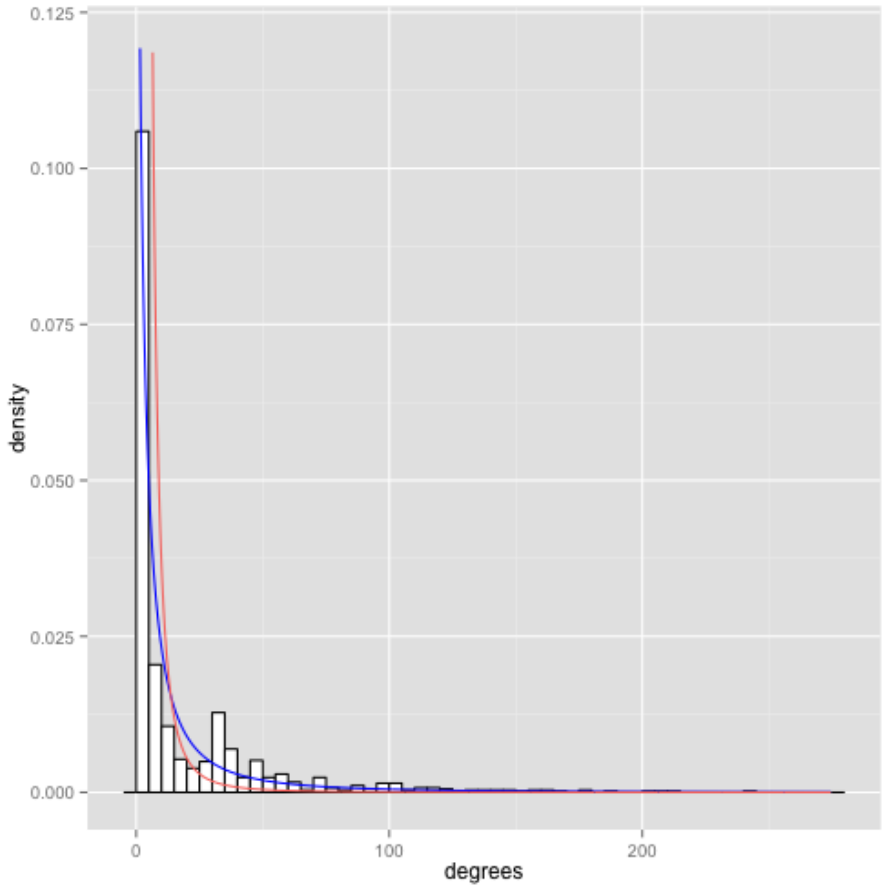


Figure 3: Degree distribution with fitted power law and lognormal functions

```
m <- split(s.ocean, f = s.ocean$LOCATION)
location.g <- list()
for (i in 1:length(levels(s.ocean$LOCATION))) {

    el.df <- data.frame(pred = m[[i]]$PREDATOR_NAME, prey = m[[i]]$PREY_NAME)

    g <- graph.edgelist(unique(as.matrix(el.df[, 1:2])))

    location.g[[i]] <- g
}
```

Plotting webs by location provides some idea about what trophic information was obtained from different sampling locations in the Southern Ocean; the labels `1:228` correspond to `levels(s.ocean$LOCATION)`:

```
par(mfrow = c(114, 2), mar = c(0.01, 0.01, 0.01, 0.01))
for (i in 1:228) {
    plot.igraph(location.g[[i]], layout = layout.circle, edge.arrow.size = 0.5,
        vertex.label = NA, vertex.size = 5)
    text(0, 0, label = i, cex = 2)
}
```

It is readily apparent from the food web plots that some sampling locations (e.g., **Bay of Morbihan, Kerguelen Islands**; **Iles Crozets**; **Seal Island**; etc.) included only a single predator with a portion of its prey. Others, like **Amanda Bay** and **Rampen**, included a single prey with some of its predators. A few locations, however, have enough species and interactions to be conisdered a near complete food web themselves (e.g., **Croker Passage**; **Scotia Sea, Weddell Sea**). Most webs have a small number of predators and prey and a few interactions.

Like the whole food web properties calculated above, indices can be calculated for each of the location subwebs.

```
web.props1 <- data.frame()
for (i in 1:228) {
    gind <- GenInd(get.adjacency(location.g[[i]], sparse = F))
    diam <- diameter(location.g[[i]])
    avpath <- average.path.length(location.g[[i]])
    cluster <- transitivity(location.g[[i]])
    cannibals <- sum(diag(get.adjacency(location.g[[i]], sparse = F)))

    degrees <- degree(location.g[[i]], mode = "all")
    indegrees <- degree(location.g[[i]], mode = "in")
    outdegrees <- degree(location.g[[i]], mode = "out")
```

```
    numBas <- length(indegrees[which(indegrees == 0)])
    numTop <- length(outdegrees[which(outdegrees == 0)])
    basal <- (numBas/gind$N) * 100
    top <- (numTop/gind$N) * 100
    int <- ((gind$N - (numBas + numTop))/gind$N) * 100

    web.props <- data.frame(N = gind$N, L = gind$Ltot, LD = gind$LD, C = gind$C,
        D = diam, AvgPath = avpath, ClCoef = cluster, Can = cannibals, Bas = basal,
        Top = top, Int = int)
    web.props1 <- rbind(web.props1, web.props)
}

print(web.props1)
```

```
      N    L      LD       C D AvgPath   ClCoef Can    Bas    Top   Int
1   232 2158  9.3017 0.04027 4   1.261 0.020466   1 25.431 65.086 9.483
2    14   27  1.9286 0.14835 1   1.000 0.000000   0 28.571 71.429 0.000
3    16   15  0.9375 0.06250 1   1.000 0.000000   0  6.250 93.750 0.000
4     6    5  0.8333 0.16667 1   1.000 0.000000   0 16.667 83.333 0.000
5    14   13  0.9286 0.07143 1   1.000 0.000000   0  7.143 92.857 0.000
6    51   98  1.9216 0.03843 3   1.203 0.060484   2 29.412 62.745 7.843
7     5    4  0.8000 0.20000 1   1.000 0.000000   0 40.000 60.000 0.000
8     4    3  0.7500 0.25000 1   1.000 0.000000   0 25.000 75.000 0.000
9    32   33  1.0312 0.03327 2   1.057 0.000000   0  9.375 87.500 3.125
10    2    1  0.5000 0.50000 1   1.000      NaN   0 50.000 50.000 0.000
11   15   38  2.5333 0.18095 1   1.000 0.000000   0 33.333 66.667 0.000
12    3    2  0.6667 0.33333 1   1.000 0.000000   0 33.333 66.667 0.000
13    2    1  0.5000 0.50000 1   1.000      NaN   0 50.000 50.000 0.000
14    2    1  0.5000 0.50000 1   1.000      NaN   0 50.000 50.000 0.000
15   19   27  1.4211 0.07895 1   1.000 0.000000   0 10.526 89.474 0.000
16   43   42  0.9767 0.02326 1   1.000 0.000000   0  2.326 97.674 0.000
17   13   15  1.1538 0.09615 1   1.000 0.000000   0 23.077 76.923 0.000
18    4    3  0.7500 0.25000 1   1.000 0.000000   0 25.000 75.000 0.000
19   17   16  0.9412 0.05882 1   1.000 0.000000   0  5.882 94.118 0.000
20    3    2  0.6667 0.33333 1   1.000 0.000000   0 66.667 33.333 0.000
21    5    4  0.8000 0.20000 1   1.000 0.000000   0 20.000 80.000 0.000
22  167  337  2.0180 0.01216 2   1.259 0.003253   0  4.192 92.216 3.593
23  141  274  1.9433 0.01388 1   1.000 0.000000   0  8.511 91.489 0.000
24    2    1  0.5000 0.50000 1   1.000      NaN   0 50.000 50.000 0.000
25   39   38  0.9744 0.02564 1   1.000 0.000000   0  2.564 97.436 0.000
26   17   22  1.2941 0.08088 1   1.000 0.000000   0 23.529 76.471 0.000
27    6    5  0.8333 0.16667 1   1.000 0.000000   0 16.667 83.333 0.000
28   24   23  0.9583 0.04167 1   1.000 0.000000   0  4.167 95.833 0.000
29   23   43  1.8696 0.08498 1   1.000 0.000000   0 26.087 73.913 0.000
30    5    4  0.8000 0.20000 1   1.000 0.000000   0 20.000 80.000 0.000
```

31	61	60	0.9836	0.01639	1	1.000	0.000000	0	1.639	98.361	0.000
32	49	48	0.9796	0.02041	1	1.000	0.000000	0	2.041	97.959	0.000
33	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
34	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
35	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
36	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
37	23	22	0.9565	0.04348	1	1.000	0.000000	0	4.348	95.652	0.000
38	30	29	0.9667	0.03333	1	1.000	0.000000	0	3.333	96.667	0.000
39	16	15	0.9375	0.06250	1	1.000	0.000000	0	6.250	93.750	0.000
40	18	17	0.9444	0.05556	1	1.000	0.000000	0	5.556	94.444	0.000
41	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
42	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
43	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
44	27	36	1.3333	0.05128	1	1.000	0.000000	0	11.111	88.889	0.000
45	26	25	0.9615	0.03846	1	1.000	0.000000	0	3.846	96.154	0.000
46	10	9	0.9000	0.10000	1	1.000	0.000000	0	10.000	90.000	0.000
47	9	14	1.5556	0.19444	1	1.000	0.000000	0	22.222	77.778	0.000
48	24	23	0.9583	0.04167	1	1.000	0.000000	0	8.333	91.667	0.000
49	47	69	1.4681	0.03191	1	1.000	0.000000	0	6.383	93.617	0.000
50	25	24	0.9600	0.04000	1	1.000	0.000000	0	4.000	96.000	0.000
51	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
52	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
53	113	2852	25.2389	0.22535	2	1.058	0.356413	10	69.912	21.239	8.850
54	32	50	1.5625	0.05040	1	1.000	0.000000	1	12.500	84.375	3.125
55	10	13	1.3000	0.14444	1	1.000	0.000000	0	30.000	70.000	0.000
56	31	30	0.9677	0.03226	1	1.000	0.000000	0	3.226	96.774	0.000
57	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
58	113	225	1.9912	0.01778	2	1.277	0.006606	0	7.965	90.265	1.770
59	38	37	0.9737	0.02632	1	1.000	0.000000	0	2.632	97.368	0.000
60	27	52	1.9259	0.07407	2	1.136	0.025140	1	7.407	85.185	7.407
61	33	32	0.9697	0.03030	1	1.000	0.000000	0	3.030	96.970	0.000
62	10	9	0.9000	0.10000	1	1.000	0.000000	0	10.000	90.000	0.000
63	40	39	0.9750	0.02500	1	1.000	0.000000	0	2.500	97.500	0.000
64	17	16	0.9412	0.05882	1	1.000	0.000000	0	5.882	94.118	0.000
65	16	15	0.9375	0.06250	1	1.000	0.000000	0	6.250	93.750	0.000
66	10	9	0.9000	0.10000	1	1.000	0.000000	0	10.000	90.000	0.000
67	28	45	1.6071	0.05952	1	1.000	0.000000	0	25.000	75.000	0.000
68	41	40	0.9756	0.02439	1	1.000	0.000000	0	2.439	97.561	0.000
69	27	43	1.5926	0.06125	1	1.000	0.000000	0	29.630	70.370	0.000
70	24	33	1.3750	0.05978	2	1.158	0.101887	1	0.000	91.667	8.333
71	5	4	0.8000	0.20000	1	1.000	0.000000	0	20.000	80.000	0.000
72	5	4	0.8000	0.20000	1	1.000	0.000000	0	20.000	80.000	0.000
73	22	21	0.9545	0.04545	1	1.000	0.000000	0	4.545	95.455	0.000
74	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
75	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
76	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000

77	7	10	1.4286	0.23810	1	1.000	0.000000	0	28.571	71.429	0.000
78	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
79	22	23	1.0455	0.04978	1	1.000	0.000000	0	9.091	90.909	0.000
80	15	16	1.0667	0.07619	2	1.158	0.083333	0	6.667	86.667	6.667
81	84	151	1.7976	0.02166	1	1.000	0.000000	0	8.333	91.667	0.000
82	25	24	0.9600	0.04000	1	1.000	0.000000	0	4.000	96.000	0.000
83	12	12	1.0000	0.09091	1	1.000	0.000000	0	16.667	83.333	0.000
84	5	3	0.6000	0.15000	1	1.000	0.000000	0	60.000	40.000	0.000
85	7	11	1.5714	0.26190	1	1.000	0.000000	0	42.857	57.143	0.000
86	33	32	0.9697	0.03030	1	1.000	0.000000	0	3.030	96.970	0.000
87	16	15	0.9375	0.06250	1	1.000	0.000000	0	6.250	93.750	0.000
88	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
89	8	7	0.8750	0.12500	1	1.000	0.000000	0	12.500	87.500	0.000
90	6	6	1.0000	0.20000	1	1.000	0.000000	0	33.333	66.667	0.000
91	72	77	1.0694	0.01506	1	1.000	0.000000	0	5.556	94.444	0.000
92	8	7	0.8750	0.12500	1	1.000	0.000000	0	12.500	87.500	0.000
93	22	21	0.9545	0.04545	1	1.000	0.000000	0	9.091	90.909	0.000
94	12	28	2.3333	0.21212	1	1.000	0.000000	0	58.333	41.667	0.000
95	13	12	0.9231	0.07692	1	1.000	0.000000	0	92.308	7.692	0.000
96	56	96	1.7143	0.03117	1	1.000	0.000000	0	5.357	94.643	0.000
97	67	115	1.7164	0.02601	1	1.000	0.000000	0	13.433	86.567	0.000
98	7	6	0.8571	0.14286	1	1.000	0.000000	0	14.286	85.714	0.000
99	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
100	42	42	1.0000	0.02439	1	1.000	0.000000	0	4.762	95.238	0.000
101	31	54	1.7419	0.05806	2	1.054	0.034722	1	9.677	87.097	3.226
102	4	2	0.5000	0.16667	1	1.000	NaN	0	50.000	50.000	0.000
103	29	27	0.9310	0.03325	1	1.000	0.000000	0	10.345	89.655	0.000
104	5	4	0.8000	0.20000	1	1.000	0.000000	0	20.000	80.000	0.000
105	29	38	1.3103	0.04680	1	1.000	0.000000	0	10.345	89.655	0.000
106	50	165	3.3000	0.06735	2	1.125	0.306778	4	4.000	88.000	8.000
107	6	5	0.8333	0.16667	1	1.000	0.000000	0	16.667	83.333	0.000
108	9	8	0.8889	0.11111	1	1.000	0.000000	0	11.111	88.889	0.000
109	32	33	1.0312	0.03327	2	1.418	0.009119	1	0.000	93.750	6.250
110	48	67	1.3958	0.02970	1	1.000	0.000000	0	6.250	93.750	0.000
111	10	9	0.9000	0.10000	1	1.000	0.000000	0	10.000	90.000	0.000
112	35	37	1.0571	0.03109	1	1.000	0.000000	0	5.714	94.286	0.000
113	50	59	1.1800	0.02408	2	1.033	0.005515	1	8.000	88.000	4.000
114	23	42	1.8261	0.08300	1	1.000	0.000000	0	8.696	91.304	0.000
115	10	16	1.6000	0.17778	1	1.000	0.000000	0	20.000	80.000	0.000
116	35	34	0.9714	0.02857	1	1.000	0.000000	0	2.857	97.143	0.000
117	103	205	1.9903	0.01951	1	1.000	0.000000	0	10.680	89.320	0.000
118	32	31	0.9688	0.03125	1	1.000	0.000000	0	3.125	96.875	0.000
119	10	9	0.9000	0.10000	1	1.000	0.000000	0	10.000	90.000	0.000
120	13	12	0.9231	0.07692	1	1.000	0.000000	0	7.692	92.308	0.000
121	22	28	1.2727	0.06061	1	1.000	0.000000	0	13.636	86.364	0.000
122	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000

123	12	16	1.3333	0.12121	1	1.000	0.000000	0	75.000	25.000	0.000
124	52	51	0.9808	0.01923	1	1.000	0.000000	0	1.923	98.077	0.000
125	37	40	1.0811	0.03003	2	1.375	0.007874	0	5.405	91.892	2.703
126	25	46	1.8400	0.07667	1	1.000	0.000000	0	8.000	92.000	0.000
127	125	967	7.7360	0.06239	3	1.074	0.311741	4	36.800	56.000	7.200
128	30	29	0.9667	0.03333	1	1.000	0.000000	0	3.333	96.667	0.000
129	31	67	2.1613	0.07204	1	1.000	0.000000	0	25.806	74.194	0.000
130	13	12	0.9231	0.07692	1	1.000	0.000000	0	7.692	92.308	0.000
131	30	30	1.0000	0.03448	1	1.000	0.000000	1	0.000	96.667	3.333
132	5	4	0.8000	0.20000	1	1.000	0.000000	0	20.000	80.000	0.000
133	11	10	0.9091	0.09091	1	1.000	0.000000	0	9.091	90.909	0.000
134	30	29	0.9667	0.03333	1	1.000	0.000000	0	3.333	96.667	0.000
135	6	5	0.8333	0.16667	1	1.000	0.000000	0	16.667	83.333	0.000
136	19	27	1.4211	0.07895	1	1.000	0.000000	0	21.053	78.947	0.000
137	21	27	1.2857	0.06429	1	1.000	0.000000	0	19.048	80.952	0.000
138	7	6	0.8571	0.14286	1	1.000	0.000000	0	28.571	71.429	0.000
139	18	17	0.9444	0.05556	1	1.000	0.000000	0	5.556	94.444	0.000
140	29	49	1.6897	0.06034	1	1.000	0.000000	0	27.586	72.414	0.000
141	4	3	0.7500	0.25000	1	1.000	0.000000	0	50.000	50.000	0.000
142	6	8	1.3333	0.26667	1	1.000	0.000000	0	33.333	66.667	0.000
143	22	51	2.3182	0.11039	1	1.000	0.000000	0	31.818	68.182	0.000
144	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
145	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
146	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
147	22	22	1.0000	0.04762	1	1.000	0.000000	1	0.000	95.455	4.545
148	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
149	27	26	0.9630	0.03704	1	1.000	0.000000	0	3.704	96.296	0.000
150	9	8	0.8889	0.11111	1	1.000	0.000000	0	11.111	88.889	0.000
151	8	7	0.8750	0.12500	1	1.000	0.000000	0	12.500	87.500	0.000
152	9	8	0.8889	0.11111	1	1.000	0.000000	0	22.222	77.778	0.000
153	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
154	6	5	0.8333	0.16667	1	1.000	0.000000	0	16.667	83.333	0.000
155	8	12	1.5000	0.21429	1	1.000	0.000000	0	37.500	62.500	0.000
156	48	47	0.9792	0.02083	1	1.000	0.000000	0	2.083	97.917	0.000
157	32	31	0.9688	0.03125	1	1.000	0.000000	0	3.125	96.875	0.000
158	33	32	0.9697	0.03030	1	1.000	0.000000	0	3.030	96.970	0.000
159	30	29	0.9667	0.03333	1	1.000	0.000000	0	3.333	96.667	0.000
160	11	10	0.9091	0.09091	1	1.000	0.000000	0	9.091	90.909	0.000
161	22	21	0.9545	0.04545	2	1.764	0.000000	0	18.182	77.273	4.545
162	25	34	1.3600	0.05667	2	1.029	0.061644	0	24.000	72.000	4.000
163	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
164	30	29	0.9667	0.03333	1	1.000	0.000000	0	3.333	96.667	0.000
165	14	13	0.9286	0.07143	1	1.000	0.000000	0	7.143	92.857	0.000
166	14	13	0.9286	0.07143	1	1.000	0.000000	0	7.143	92.857	0.000
167	72	75	1.0417	0.01467	2	1.051	0.000000	1	5.556	91.667	2.778
168	56	62	1.1071	0.02013	1	1.000	0.000000	0	3.571	96.429	0.000

169	46	201	4.3696	0.09710	1	1.000	0.000000	0	19.565	80.435	0.000
170	41	378	9.2195	0.23049	1	1.000	0.000000	0	34.146	65.854	0.000
171	5	5	1.0000	0.25000	1	1.000	0.000000	0	40.000	60.000	0.000
172	55	756	13.7455	0.25455	1	1.000	0.000000	0	50.909	49.091	0.000
173	24	52	2.1667	0.09420	1	1.000	0.000000	0	33.333	66.667	0.000
174	7	6	0.8571	0.14286	1	1.000	0.000000	0	14.286	85.714	0.000
175	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
176	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
177	58	65	1.1207	0.01966	2	1.030	0.013663	1	1.724	96.552	1.724
178	95	114	1.2000	0.01277	2	1.333	0.015446	2	0.000	97.895	2.105
179	16	20	1.2500	0.08333	1	1.000	0.000000	0	12.500	87.500	0.000
180	29	50	1.7241	0.06158	1	1.000	0.000000	0	31.034	68.966	0.000
181	34	73	2.1471	0.06506	1	1.000	0.000000	0	20.588	79.412	0.000
182	12	20	1.6667	0.15152	1	1.000	0.000000	0	16.667	83.333	0.000
183	8	9	1.1250	0.16071	1	1.000	0.000000	0	25.000	75.000	0.000
184	6	4	0.6667	0.13333	1	1.000	0.000000	0	33.333	66.667	0.000
185	160	527	3.2938	0.02072	2	1.165	0.069385	2	16.875	75.000	8.125
186	34	34	1.0000	0.03030	1	1.000	0.000000	1	0.000	97.059	2.941
187	46	67	1.4565	0.03237	1	1.000	0.000000	0	17.391	82.609	0.000
188	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
189	10	12	1.2000	0.13333	1	1.000	0.000000	0	20.000	80.000	0.000
190	19	51	2.6842	0.14912	1	1.000	0.000000	0	73.684	26.316	0.000
191	15	14	0.9333	0.06667	1	1.000	0.000000	0	6.667	93.333	0.000
192	27	46	1.7037	0.06553	2	1.098	0.000000	0	22.222	74.074	3.704
193	24	35	1.4583	0.06341	1	1.000	0.000000	0	16.667	83.333	0.000
194	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
195	3	2	0.6667	0.33333	1	1.000	0.000000	0	33.333	66.667	0.000
196	15	17	1.1333	0.08095	1	1.000	0.000000	0	46.667	53.333	0.000
197	63	84	1.3333	0.02151	1	1.000	0.000000	0	6.349	93.651	0.000
198	12	11	0.9167	0.08333	1	1.000	0.000000	0	8.333	91.667	0.000
199	41	40	0.9756	0.02439	1	1.000	0.000000	0	2.439	97.561	0.000
200	5	4	0.8000	0.20000	1	1.000	0.000000	0	20.000	80.000	0.000
201	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
202	24	23	0.9583	0.04167	1	1.000	0.000000	0	4.167	95.833	0.000
203	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
204	23	22	0.9565	0.04348	1	1.000	0.000000	0	4.348	95.652	0.000
205	4	3	0.7500	0.25000	1	1.000	0.000000	0	25.000	75.000	0.000
206	2	1	0.5000	0.50000	1	1.000	NaN	0	50.000	50.000	0.000
207	14	13	0.9286	0.07143	1	1.000	0.000000	0	7.143	92.857	0.000
208	11	10	0.9091	0.09091	1	1.000	0.000000	0	9.091	90.909	0.000
209	23	21	0.9130	0.04150	1	1.000	0.000000	0	8.696	91.304	0.000
210	38	37	0.9737	0.02632	1	1.000	0.000000	0	2.632	97.368	0.000
211	8	7	0.8750	0.12500	1	1.000	0.000000	0	12.500	87.500	0.000
212	83	81	0.9759	0.01190	2	1.036	0.000000	0	2.410	96.386	1.205
213	7	6	0.8571	0.14286	1	1.000	0.000000	0	14.286	85.714	0.000
214	5	4	0.8000	0.20000	1	1.000	0.000000	0	40.000	60.000	0.000

```
215  27   34  1.2593 0.04843 1   1.000 0.000000   0 11.111 88.889 0.000
216  32  196  6.1250 0.19758 1   1.000 0.339161   3 12.500 78.125 9.375
217   8    7  0.8750 0.12500 1   1.000 0.000000   0 12.500 87.500 0.000
218   3    2  0.6667 0.33333 1   1.000 0.000000   0 33.333 66.667 0.000
219  22   21  0.9545 0.04545 1   1.000 0.000000   0  4.545 95.455 0.000
220  24   23  0.9583 0.04167 1   1.000 0.000000   0  4.167 95.833 0.000
221  33   32  0.9697 0.03030 1   1.000 0.000000   0  3.030 96.970 0.000
222  15   16  1.0667 0.07619 1   1.000 0.000000   0 26.667 73.333 0.000
223  11   10  0.9091 0.09091 1   1.000 0.000000   0  9.091 90.909 0.000
224  18   28  1.5556 0.09150 1   1.000 0.000000   0 27.778 72.222 0.000
225  18   25  1.3889 0.08170 1   1.000 0.000000   0 22.222 77.778 0.000
226  20   26  1.3000 0.06842 1   1.000 0.000000   0 30.000 70.000 0.000
227  12   18  1.5000 0.13636 1   1.000 0.000000   0 25.000 75.000 0.000
228   9    7  0.7778 0.09722 1   1.000 0.000000   0 22.222 77.778 0.000
```

Because there are so many different locations (228) the dataframe of web properties becomes a bit unwieldy. Plotting the different indices is a useful way to examine some of the properties of the different locations' food webs. First, a histogram of the number of nodes (N) in each web shows that most of the webs invovle less than 50 species, but a few are greater than 150 species.

```
ggplot(web.props1) + geom_histogram(aes(x = N), binwidth = 5)
```

A plot of connectance (C) against size (N) shows the expected relationship of a decline in connectance with size. It is also evident that most of the food webs in this study have a connectance less than 0.1. A number of webs have a connectance of 0.5, but those represent the locations with webs that are only two species with one interaction.

```
ggplot(web.props1) + geom_point(aes(x = N, y = C))
```

```
nn <- matrix(c(web.props1$Bas, web.props1$Int, web.props1$Top), nrow = 3, ncol = 228,
    byrow = T)
colnames(nn) <- as.character(1:228)

barplot(nn, col = c("blue", "yellow", "darkgreen"), xlab = "Web", ylab = "Percent")
```

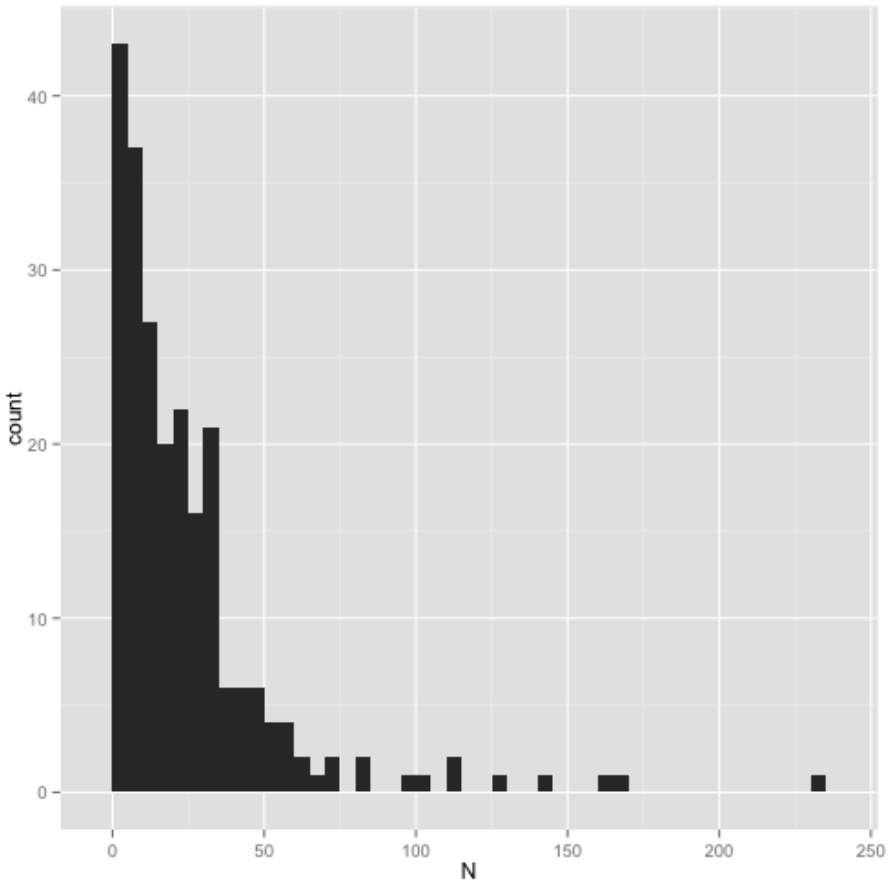


Figure 5: Histogram of number of species per location

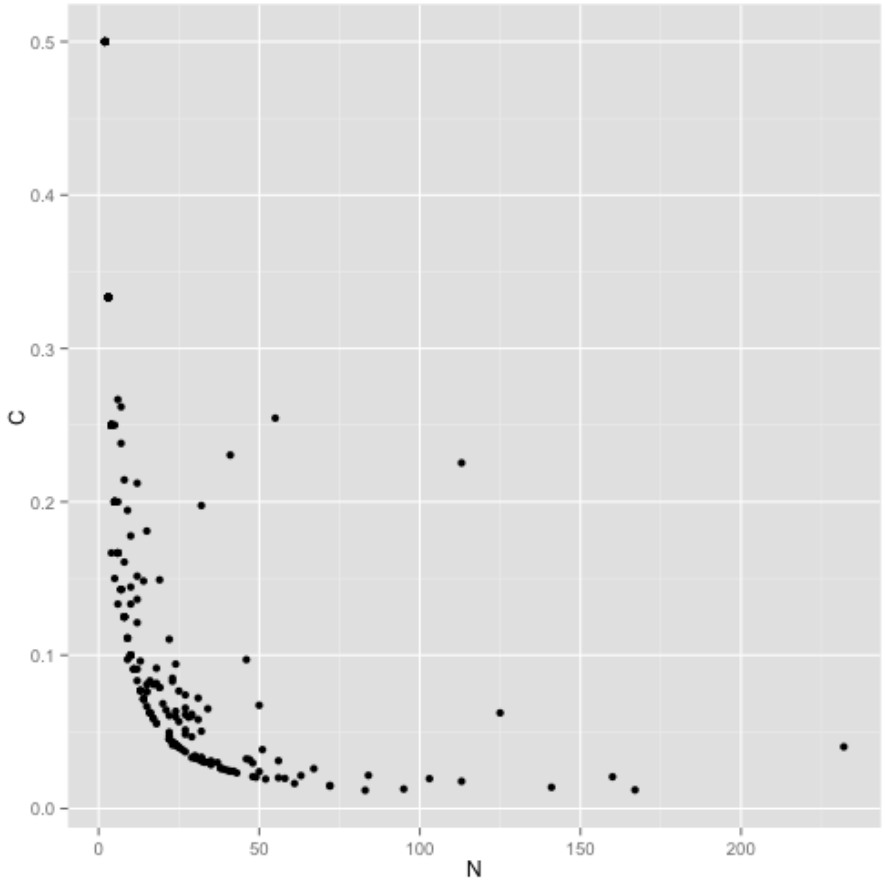


Figure 6: Plot connectance agains size

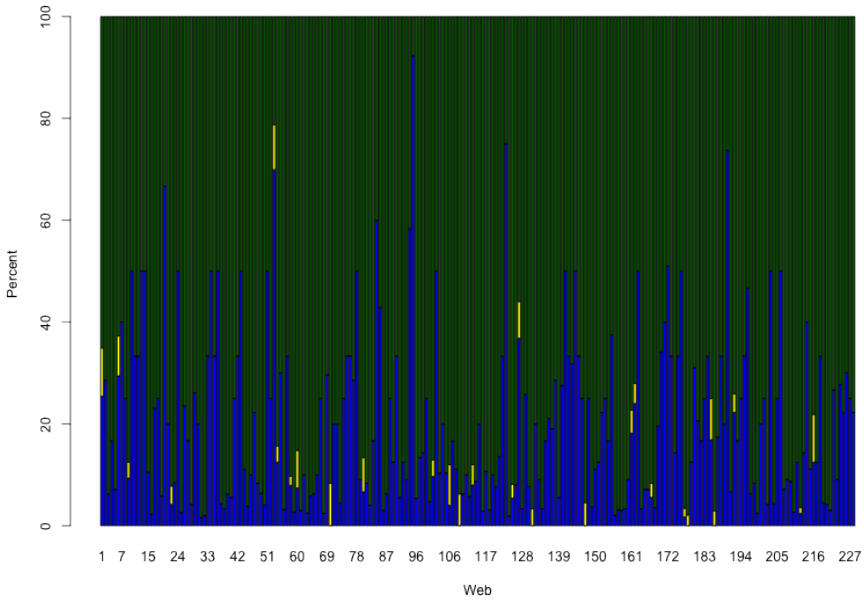


Figure 7: Proportions basal, intermediate, top

By year

```
so.ode <- as.character(s.ocean$OBSERVATION_DATE_END)
so.ode.split <- strsplit(so.ode, split = "/")

year <- c()
for (i in 1:length(so.ode.split)) {
    year[i] <- so.ode.split[[i]][3]
}
s.ocean2 <- cbind(s.ocean, year)

m2 <- split(s.ocean2, f = s.ocean2$year)
year.g <- list()
for (i in 1:length(levels(s.ocean2$year))) {

    el.df <- data.frame(pred = m2[[i]]$PREDATOR_NAME, prey = m2[[i]]$PREY_NAME)

    g <- graph.edgelist(unique(as.matrix(el.df[, 1:2])))

    year.g[[i]] <- g
}
```

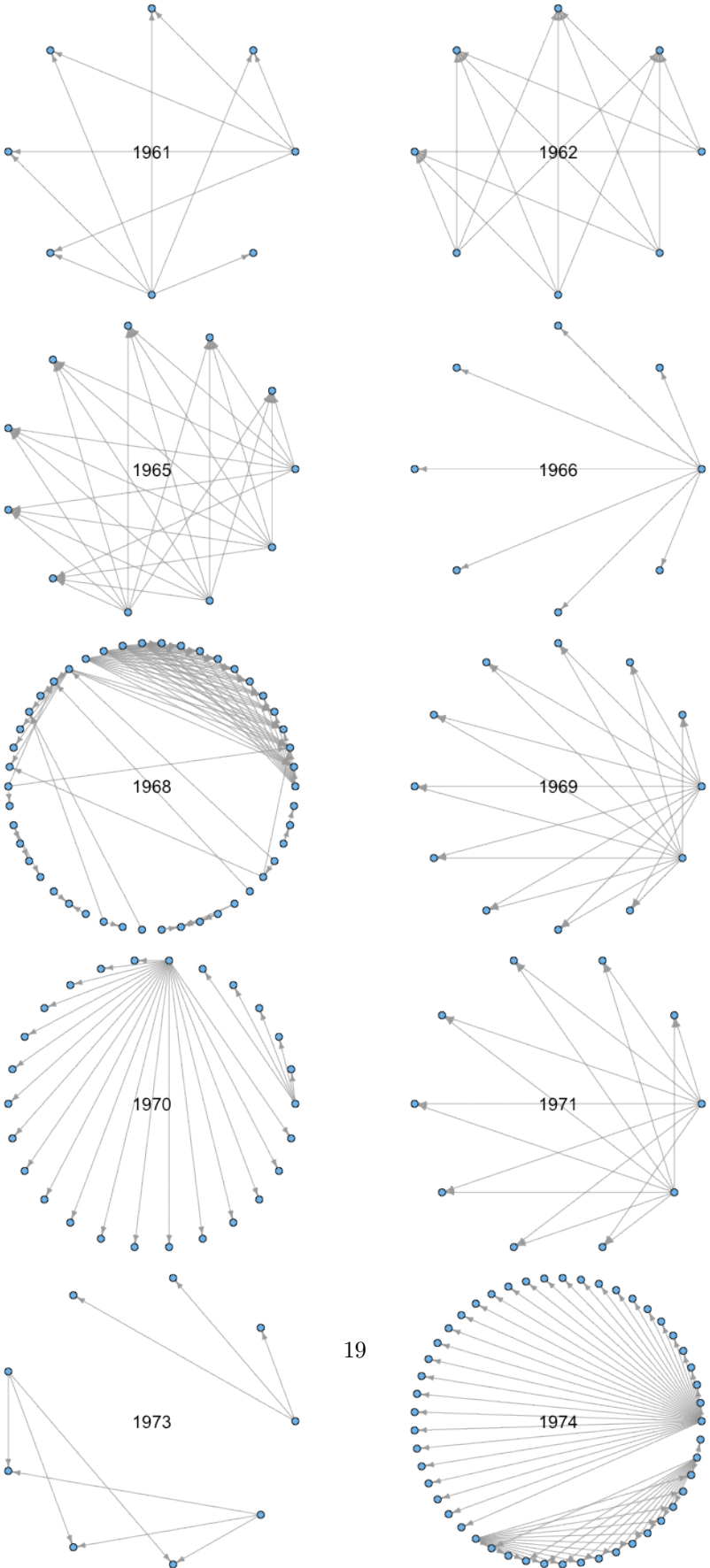
Plot webs by year

```
par(mfrow = c(23, 2), mar = c(0.01, 0.01, 0.01, 0.01))
for (i in 1:45) {
    plot.igraph(year.g[[i]], layout = layout.circle, edge.arrow.size = 0.5,
        vertex.label = NA, vertex.size = 5)
    text(0, 0, label = levels(s.ocean2$year)[i], cex = 2)
}
```

```
web.props2 <- data.frame()
for (i in 1:45) {
    gind <- GenInd(get.adjacency(year.g[[i]], sparse = F))
    diam <- diameter(year.g[[i]])
    avpath <- average.path.length(year.g[[i]])
    cluster <- transitivity(year.g[[i]])
    cannibals <- sum(diag(get.adjacency(year.g[[i]], sparse = F)))

    degrees <- degree(year.g[[i]], mode = "all")
    indegrees <- degree(year.g[[i]], mode = "in")
    outdegrees <- degree(year.g[[i]], mode = "out")

    numBas <- length(indegrees[which(indegrees == 0)])
    numTop <- length(outdegrees[which(outdegrees == 0)])
    basal <- (numBas/gind$N) * 100
    top <- (numTop/gind$N) * 100
    int <- ((gind$N - (numBas + numTop))/gind$N) * 100

    web.props <- data.frame(N = gind$N, L = gind$Ltot, LD = gind$LD, C = gind$C,
        D = diam, AvgPath = avpath, ClCoef = cluster, Can = cannibals, Bas = basal,
        Top = top, Int = int)
    web.props2 <- rbind(web.props2, web.props)
}
```

```
print(web.props2)
```

```
     N    L      LD        C D AvgPath    ClCoef Can    Bas   Top      Int
1    8   11  1.3750 0.196429 1   1.000 0.0000000   0 25.000 75.00  0.0000
2    8   16  2.0000 0.285714 1   1.000 0.0000000   0 50.000 50.00  0.0000
3   11   28  2.5455 0.254545 1   1.000 0.0000000   0 36.364 63.64  0.0000
4    8    7  0.8750 0.125000 1   1.000 0.0000000   0 12.500 87.50  0.0000
5   46   88  1.9130 0.042512 2   1.093 0.0000000   0 36.957 58.70  4.3478
6   12   20  1.6667 0.151515 1   1.000 0.0000000   0 16.667 83.33  0.0000
7   26   24  0.9231 0.036923 1   1.000 0.0000000   0  7.692 92.31  0.0000
8   10   16  1.6000 0.177778 1   1.000 0.0000000   0 20.000 80.00  0.0000
```


1961
1962
1965
1966
1968
1969
1970
1971
1973
1974

9	9	9	1.0000	0.125000	1	1.000	0.0000000	0	33.333	66.67	0.0000
10	49	58	1.1837	0.024660	1	1.000	0.0000000	0	6.122	93.88	0.0000
11	70	83	1.1857	0.017184	1	1.000	0.0000000	0	4.286	95.71	0.0000
12	28	38	1.3571	0.050265	1	1.000	0.0000000	0	14.286	85.71	0.0000
13	31	34	1.0968	0.036559	1	1.000	0.0000000	0	16.129	83.87	0.0000
14	95	157	1.6526	0.017581	1	1.000	0.0000000	0	14.737	85.26	0.0000
15	90	299	3.3222	0.037328	2	1.010	0.2691166	4	14.444	81.11	4.4444
16	94	139	1.4787	0.015900	2	1.042	0.0115607	1	11.702	86.17	2.1277
17	208	433	2.0817	0.010057	2	1.207	0.0101225	1	12.981	82.69	4.3269
18	299	4257	14.2375	0.047777	3	1.420	0.3121464	13	31.104	60.54	8.3612
19	109	163	1.4954	0.013846	2	1.190	0.0085511	1	9.174	87.16	3.6697
20	125	207	1.6560	0.013355	2	1.205	0.0144695	1	14.400	82.40	3.2000
21	120	219	1.8250	0.015336	1	1.000	0.0000000	0	10.833	89.17	0.0000
22	104	202	1.9423	0.018857	2	1.151	0.0000000	0	8.654	90.38	0.9615
23	155	825	5.3226	0.034562	3	1.119	0.0086548	0	21.290	70.97	7.7419
24	53	65	1.2264	0.023585	2	1.133	0.0164835	0	11.321	84.91	3.7736
25	129	224	1.7364	0.013566	2	1.189	0.0024430	1	6.977	89.15	3.8760
26	145	185	1.2759	0.008860	3	1.464	0.0132890	2	9.655	85.52	4.8276
27	130	210	1.6154	0.012522	3	1.290	0.0186722	1	10.769	86.92	2.3077
28	205	1230	6.0000	0.029412	4	1.336	0.0006669	1	14.634	81.95	3.4146
29	215	878	4.0837	0.019083	3	1.421	0.0179806	0	9.767	86.98	3.2558
30	213	382	1.7934	0.008460	3	1.799	0.0149495	1	5.164	90.61	4.2254
31	189	530	2.8042	0.014916	4	1.656	0.1237898	5	12.698	80.95	6.3492
32	205	422	2.0585	0.010091	3	1.099	0.0032805	1	11.707	85.37	2.9268
33	181	298	1.6464	0.009147	3	1.107	0.0050220	0	9.392	88.95	1.6575
34	183	599	3.2732	0.017985	3	1.290	0.0505352	1	10.929	78.69	10.3825
35	222	464	2.0901	0.009457	2	1.241	0.0189959	1	6.306	92.34	1.3514
36	161	296	1.8385	0.011491	3	1.317	0.0184049	1	6.832	89.44	3.7267
37	135	209	1.5481	0.011553	3	1.256	0.0156018	1	5.926	91.85	2.2222
38	60	87	1.4500	0.024576	3	1.442	0.0403769	1	6.667	88.33	5.0000
39	121	312	2.5785	0.021488	3	1.539	0.0496710	2	9.917	80.99	9.0909
40	57	69	1.2105	0.021617	2	1.374	0.0299700	2	1.754	94.74	3.5088
41	183	269	1.4699	0.008077	3	1.708	0.0408666	3	3.279	93.44	3.2787
42	63	62	0.9841	0.015873	1	1.000	0.0000000	0	1.587	98.41	0.0000
43	82	93	1.1341	0.014002	1	1.000	0.0000000	0	7.317	92.68	0.0000
44	71	78	1.0986	0.015694	1	1.000	0.0000000	0	4.225	95.77	0.0000
45	3	2	0.6667	0.333333	1	1.000	0.0000000	0	33.333	66.67	0.0000