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.
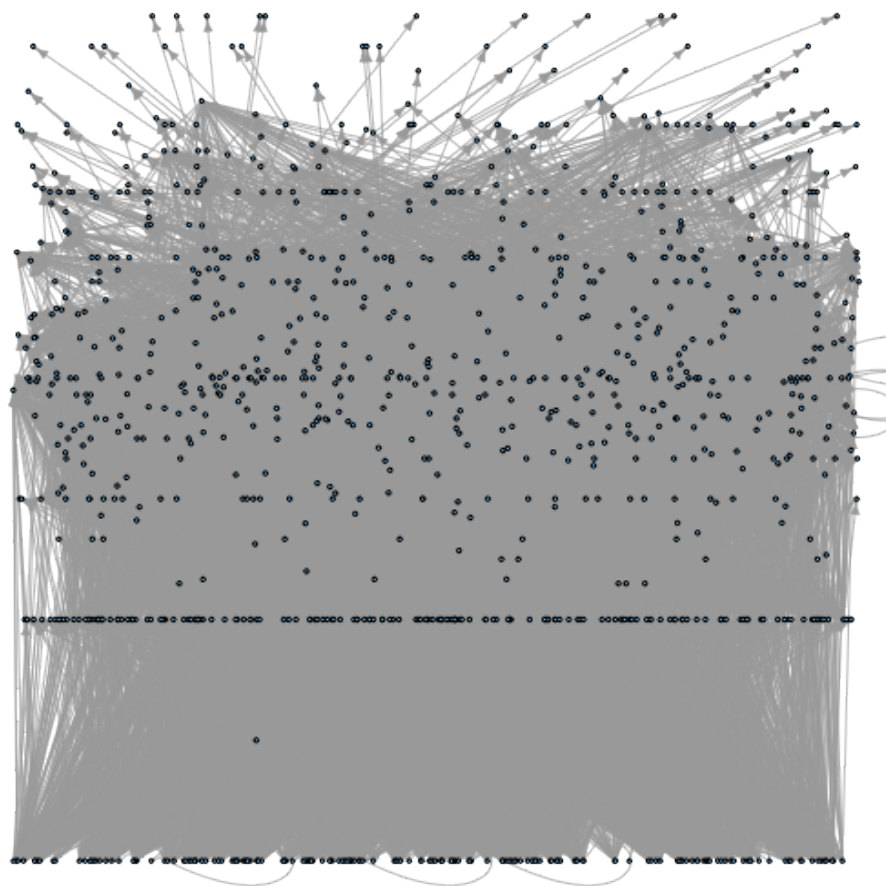
Figure 1: plot of chunk wholeFW

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.

```r
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")
```
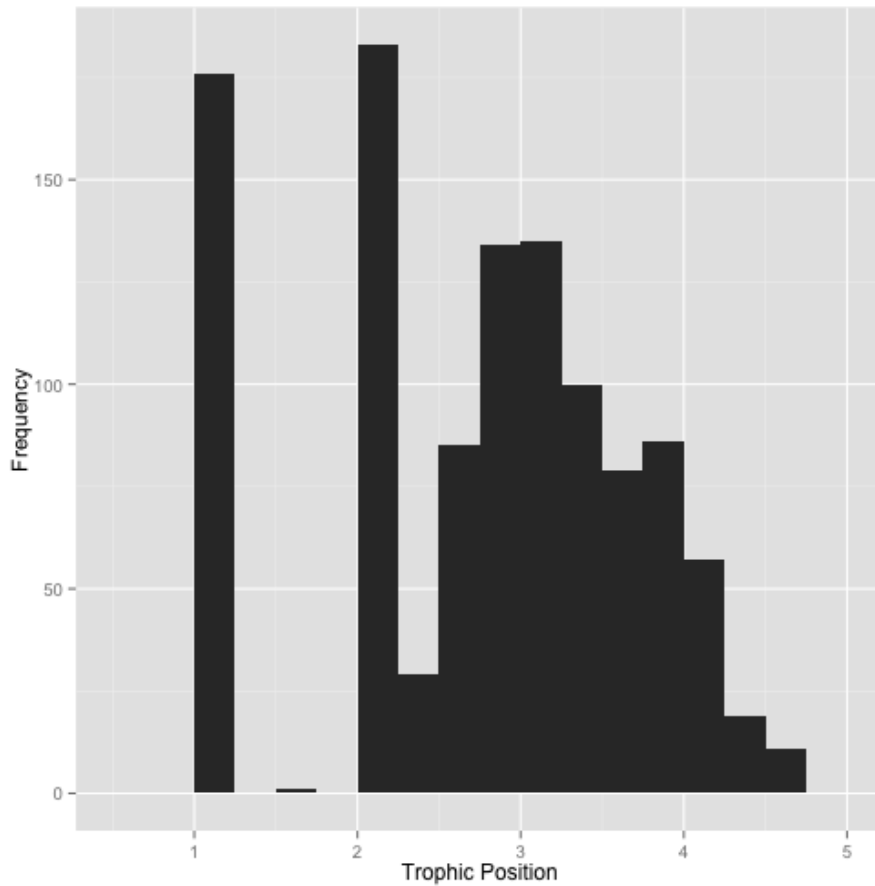

Figure 2: plot of chunk TLplot

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*
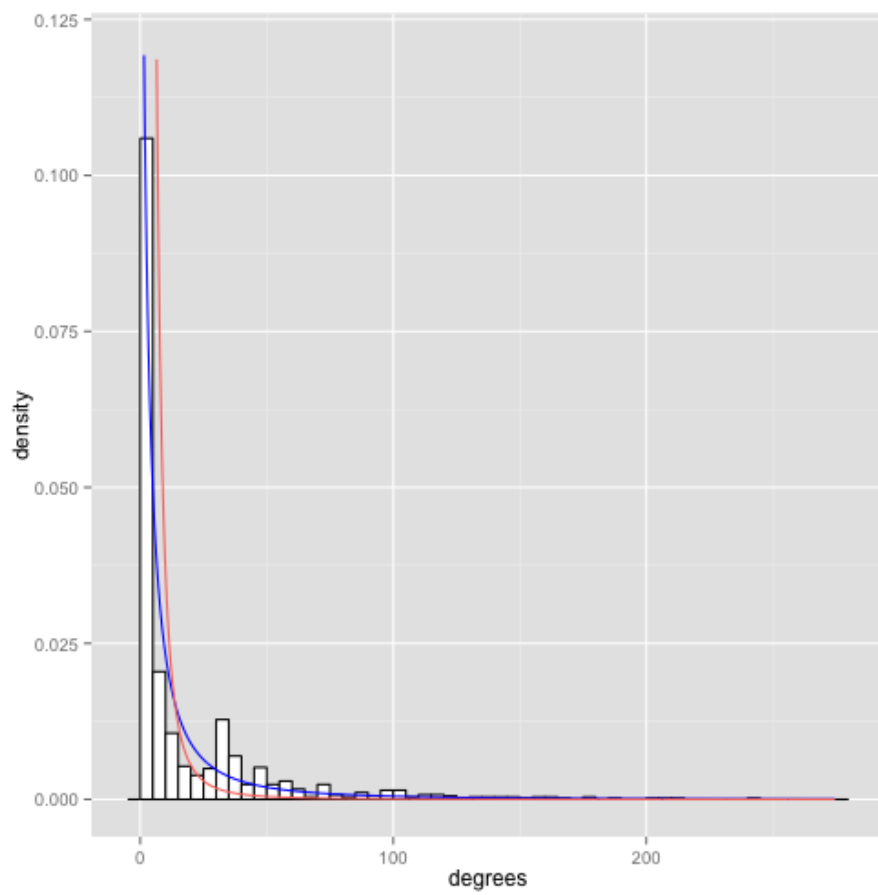
Figure 3: plot of chunk degreeDIST

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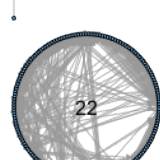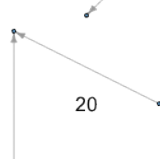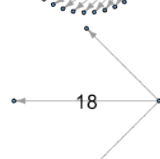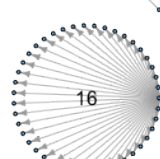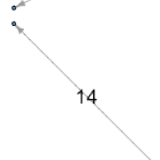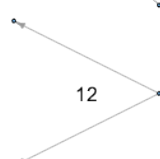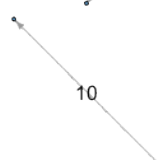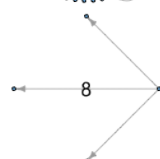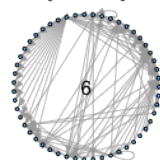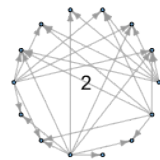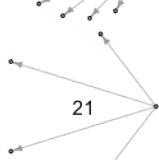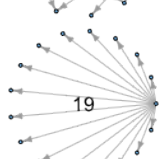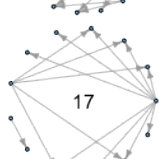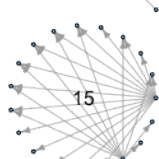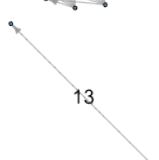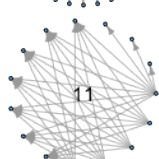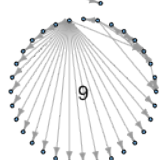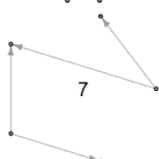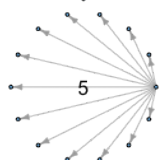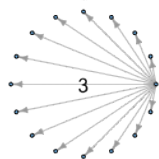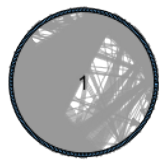
```r
    numBas <- length(indegrees[which(indegrees == 0)])
    numTop <- length(outdegrees[which(outdegrees == 0)])
    basal <- (numBas/gind$N) * 100
    top <- (numTop/gind$N) * 100
    int <- ((gind$N - (numBas + numTop))/gind$N) * 100

    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 prop-
erties 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")
```
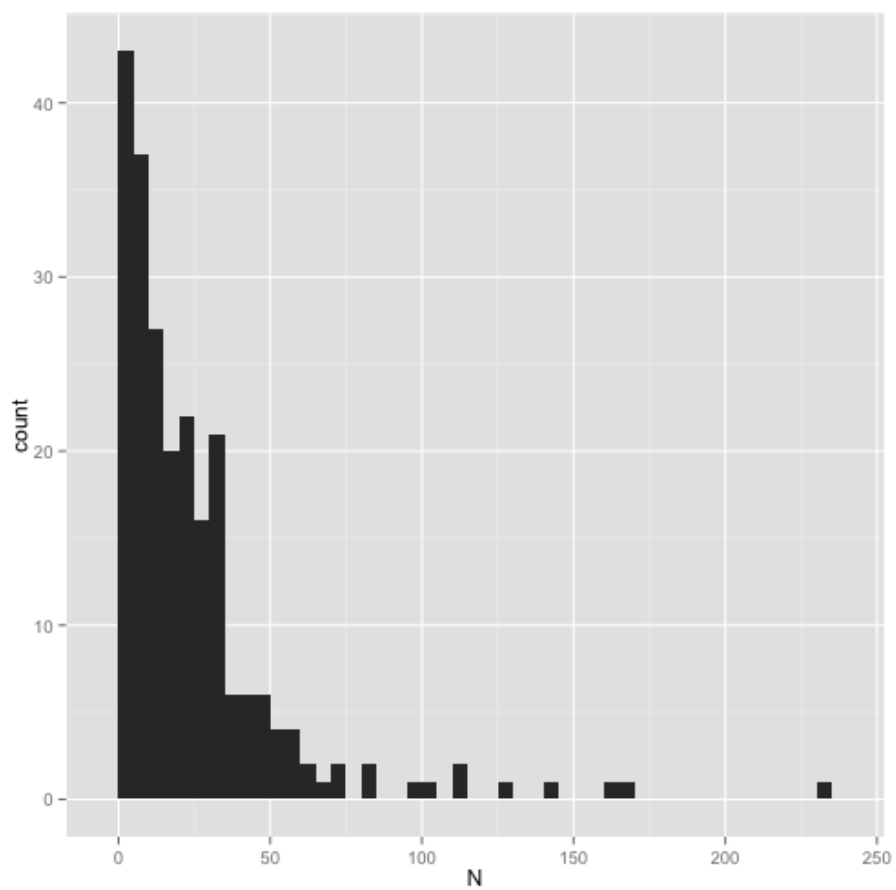
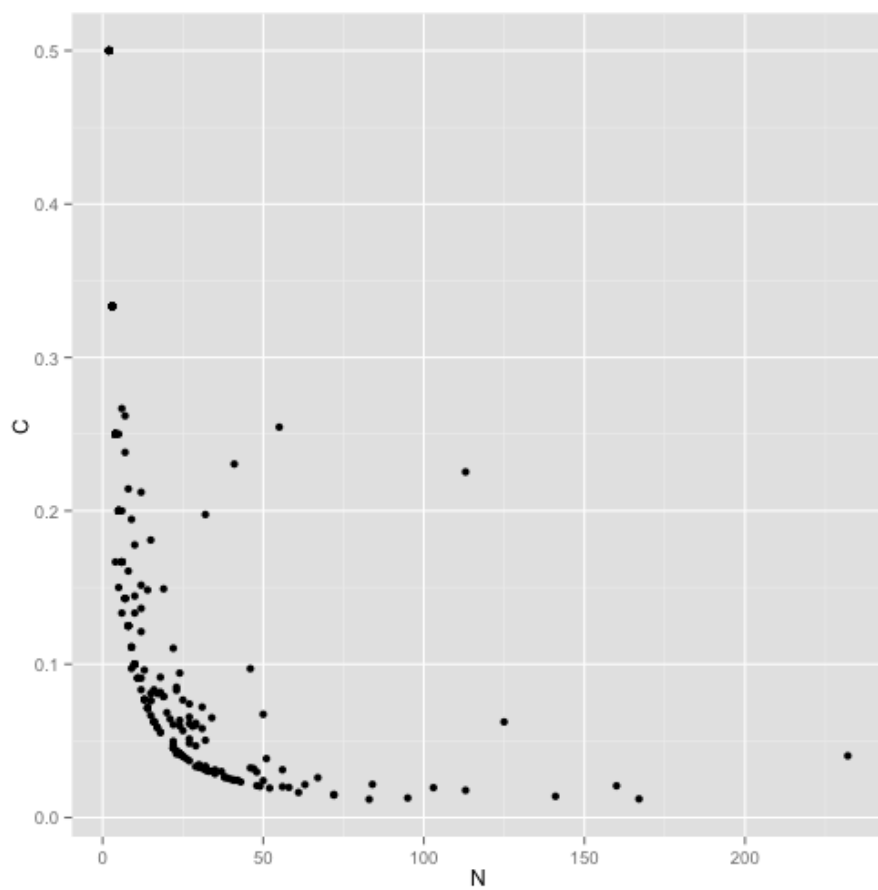Figure 5: plot of chunk unnamed-chunk-9
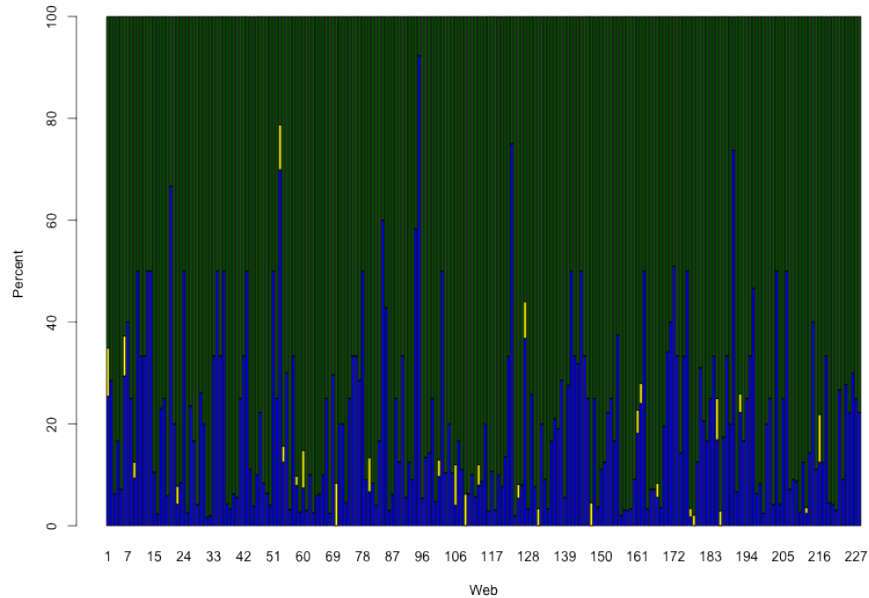
Figure 6: plot of chunk unnamed-chunk-10

Figure 7: plot of chunk unnamed-chunk-11

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 = m[[i]]$PREDATOR_NAME, prey = m[[i]]$PREY_NAME)

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

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

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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)
}
```