An algorithm for calculation of degree distribution and detection of network type: with application in food webs

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Abstract
In present study a Java algorithm to calculate degree distribution and detect network type was presented. Some indices, e.g., aggregation index, coefficient of variation, skewness, etc., were first suggested for detecting network type. Network types of some food webs reported in Interaction Web Database were determined using the algorithm. The results showed that the degree of most food webs was power law or exponentially distributed and they were complex networks. Different from classical distribution patterns (bionomial distribution, Poisson distribution, and power law distribution, etc.), both network type and network complexity can be calculated and compared using the indices above. We suggest that they should be used in the network analysis. In addition, we defined $E, E=s^2-\bar{u}$, where $\bar{u}$ and $s^2$ is mean and variance of degree respectively, as the entropy of network. A more complex network has the larger entropy. If $E \leq 0$, the network is a random network and, it is a complex network if $E > 0$.

Keywords network; food web; type; degree distribution; aggregation indices; entropy; algorithm; Java.

1 Introduction
The food web is a set of species connected by trophic relations. It is an ecological network made of interactive species. Biodiversity, ecosystem structure and function, etc., can be represented by food webs. There are two kinds of food webs, i.e., the one with autotrophic species as base species and the one with scavenger animals as base species (Gonenc et al., 2007). The complexity and trophic levels of food web determine the stability, resilience and robustness of the community. An ecosystem resists the extinction of species if its food web is complex enough. The species loss in food web would at some extent detriment the stability of ecosystem.

Food webs have long been the center of ecological studies. They began with text and table expression and then linear and spatial expression. As the emerging of large numbers of algorithms and software, the studies of network structure are now becoming the focus of food webs. These algorithms and software have been used to explore the ecosystem stability and robustness. For example, they are used to study degree distribution, connectance and network size (Dunne et al., 2002). Odum (1983) pointed out that the community stability could be measured by energy path in the food web. MacArthur (1955) thought that stability may be increased by the increase of links in the food web. Pimm et al. (1991) have discussed effects of different models of food webs on ecosystem structure, stability and robustness. It was found that the mechanism of evolution and population size will affect food web topology (Rossberg et al., 2005). In addition, habitat destruction and
climate change are likely to cause the extinction of key species. Once key species extinct, the robustness of food web will be profoundly affected (Allesina et al., 2009).

The networks, including food webs, met in last decade become more and more complex. There are usually large numbers of vertices and links in a complex network (Ibrahim et al., 2011; Goemann et al., 2011; Kuang and Zhang, 2011; Martinez-Antonio, 2011; Paris and Bazzoni, 2011; Rodriguez and Infante, 2011; Tacutu et al., 2011). It is hard to analyze such networks by using classical methods or algorithms. Graph theory, optimization, statistics, and stochastic processes, etc., are becoming the scientific basis and effective tools for studying complex networks (Ferrarini, 2011; Zhang, 2011a, b; Zhang, 2012). Degree distribution and network type is one of the research focuses based on those tools and methods. In this aspect some ecological networks have been proved to be scale-free networks (Zhang, 2011a).

The present study aimed to present a Java algorithm to calculate degree distribution and detect network type. Some indices were first suggested by us for detecting network type. Network types of food webs reported in Interaction Web Database were determined using the algorithm.

2 Materials and Methods
2.1 Methods
Suppose that the portion of nodes with \( k \)-degree is \( p_k \), the degree will thus be a random variable and its distribution is degree distribution. It has found that in the random network, degree distribution is binomial distribution, and its limit model is Poisson distribution. In a random network, the majority of vertices have the same degree with the average. In the complex network, degree distribution is a power law distribution, and the network is called a scale-free network (Barabasi and Albert, 1999; Barabasi, 2009). A property of the scale-free network is that the structure and the evolution of network are inseparable. Scale-free networks constantly change because of the arrival of nodes and links (Barabasi and Albert, 1999).

In present algorithm, in addition to power law distribution, binomial distribution, Poisson distribution, and exponential distribution (Zhang, 2012), some other indices and methods were also used to detect network type:

1. Skewness. This index is used to measure the degree of skewness of a degree distribution relative to the symmetric distribution, for example, the normal distribution (\( S=0 \)) (Sokal and Rohlf, 1995):

\[
S = v \sum (d_i - \bar{d})^2 / [(v-1)(v-2)s^3].
\]

where \( \bar{d}, s^2 \): mean and variance of degree; \( v \): number of nodes; \( d_i \): degree of node \( i, i=1,2,...,v \). The smaller the skewness is, the more complex the network is.

2. Coefficient of variation. In a random network, the majority of nodes have the same degree as the average. The coefficient of variation, \( H \), can be used to describe the type of a network (Zhang, 2007):

\[
H = s^2 / \bar{d},
\]

\[
\bar{d} = \sum d_i / v,
\]

\[
s^2 = \sum (d_i - \bar{d})^2 / (v-1),
\]

where \( \bar{d}, s^2 \): mean and variance of degree; \( v \): number of nodes; \( d_i \): the degree of node \( i, i=1,2,...,v \). The network is a random network, if \( H \leq 1 \). Calculate \( \chi^2 = (v-1)H, \) and if \( \chi^2 < \chi^2_{\alpha}^2 \) (\( \alpha=0.05 \)), the network is a complete random network. It is a complex network, if \( H > 1 \), and to some extent, network complexity increases with \( H \).

Here we define \( E, E = s^2 - \bar{d} \), as the entropy of network. A more complex network has the larger entropy. If \( E \leq 0 \) the network is a random network and it is a complex network if \( E > 0 \).
(3) Aggregation index. Network type can be determined by using the following aggregation index (Zhang, 2007):

\[ H = v^* \frac{\sum d_i(d_i-1)}{\sum d_i(\sum d_i-1)} \]

The network is a random network, if \( H \leq 1 \). Calculate \( \chi^2 = H(\sum d_i-1)+v-\sum d_i \), and if \( \chi^2 < \chi^2_\alpha (v-1) \), the network is a complete random network. It is a complex network if \( H > 1 \), and network complexity increases with \( H \).

The following code is the Java algorithm, netType, to calculate degree distribution and detect network type:

```java
public class netType {
    public static void main(String[] args){
        int i,j,v,n;
        if (args.length!=1)
            System.out.println("You must input the name of table in the database. For example, you may type the following in the command window: java netType nettype, where nettype is the name of table. Graph is stored in the table using two arrays listing and was transformed to adjacency matrix by method adjMatTwoArr.\)
        String tablename=args[0];
        readDatabase readdata=new readDatabase("dataBase",tablename, 3);
        n = readdata.m;
        int a[]=new int[n+1];
        int b[]=new int[n+1];
        int c[]=new int[n+1];
        int d[][]=new int[n+1][n+1];
        for(i=1;i<=n;i++) {
            a[i]=(Integer.valueOf(readdata.data[i][1])).intValue();
            b[i]=(Integer.valueOf(readdata.data[i][2])).intValue();
            c[i]=(Integer.valueOf(readdata.data[i][3])).intValue();
        }
        adjMatTwoArr adj=new adjMatTwoArr();
        adj.dataTrans(a,b,c);
        v=adj.v;
        for(i=1;i<=v;i++)
            for(j=1;j<=v;j++) d[i][j]=adj.d[i][j];
        netType(v,d); }
    public static void netType(int v, int d[][]) {
        int i,j,k,l,m,rr,ty,r;
        double it,pp,ss,qq,k1,k2, chi,mean,var,skew;
        int deg[]=new int[v+1];
        int p[]=new int[v+1];
        double fr[]=new double[v+1];
        double pr[]=new double[v+1];
        for(i=1;i<=v;i++) {
            deg[i]=0;
            for(j=1;j<=v;j++)
                if (Math.abs(d[i][j])==1) deg[i]++;
            if (d[i][i]==1) deg[i]++;
            if (d[i][i]==2) deg[i]++;
            if (d[i][i]==3) deg[i]++;
            if (d[i][i]==5) deg[i]++;
        }
        for(i=1;i<=v;i++)
            if (deg[i]>1) p[i]=i;
        for(i=1;i<=v;i++)
            if (deg[i]==1)
                deg[i]=2;
        for(i=1;i<=v;i++)
            if (deg[i]==2)
                deg[i]=3;
        for(i=1;i<=v;i++)
            if (deg[i]==3)
                deg[i]=4;
        for(i=1;i<=v;i++)
            if (deg[i]==4)
                deg[i]=5;
        for(i=1;i<=v;i++)
            if (deg[i]==5)
                deg[i]=6;
        pp=qq=0;
        System.out.println("Ranks  Vertice  Degrees/n");
        for(i=1;i<=v;i++)
            System.out.println(" +i+  +p[i]+  +deg[i]+" );
        pp+=deg[i];
    }
```
qq+=deg[i]*(deg[i]-1); }
System.out.println();
rr=10;
it=(deg[1]-deg[v])/(double)rr;
for(i=1;i<=10;i++) {
fr[i]=0;
for(j=1;j<=v;j++)
if ((deg[j]>=(deg[v]+(i-1)*it)) & (deg[j]<(deg[v]+i*it))) fr[i]++; }
System.out.println("Frequency distribution of degrees:");
for(i=1;i<=10;i++)
System.out.println();
for(i=1;i<=10;i++)
System.out.println("{} ");
mean=pp/v;
ss=0;
for(i=1;i<=v;i++)
ss+=Math.pow(deg[i]-mean,2);
var=ss/(v-1);
skew=v/Math.sqrt(var);
System.out.println("Skewness of degree distribution: "+skew+"n");
System.out.println("Aggregation index of the network: "+h);
if (h==1) System.out.println("It is a random network.n");
if (h>1) System.out.println("It is a complex network.n");
h=var/mean;
System.out.println("Variation coefficient H of the network: "+h);
for(i=1;i<=10;i++)
System.out.println(deg[i]+it/2.0+(i-1)*it+" ");
for(i=1;i<=10;i++)
System.out.println(deg[i]+" ");
mean=pp/v;
ss=0;
for(i=1;i<=v;i++)
ss+=i*fr[i+1];
pp=ss/(v*(rr-1));
qq=1-pp;
pr[0]=Math.pow(qq,rr-1);
for(r=1;r<=rr-1;r++) pr[r]=mean/r*pr[r-1];
chi=xsquare(v, rr, pr, fr);
System.out.println("Binomial distribution Chi-square=+chi");
System.out.println("Binomial p=+pp");
k1=20.09;
coincidence(ty, k1, chi);
ty=2;
//Poisson distri., pr = e^-\lambda *r/r!, r=0,1,2,...
pr[0]=Math.exp(-mean);
for(r=1;r<=rr-1;r++) pr[r]=mean/r*pr[r-1];
chi=xsquare(v, rr, pr, fr);
System.out.println("Poisson distribution chi-square=+chi");
System.out.println(" Poisson lamda=+mean");
k1=20.09;
coincidence(ty, k1, chi);
ty=3;
//Exponential distri., F(x) =1-e^-\lambda x, x\geq0
chi=0;
for(i=1;i<=10;i++)
{k1=deg[v]+it/2.0+(i-1)*it;
k2=deg[v]+it/2.0+i*it;
pp=v*(Math.exp(-k1/mean)-Math.exp(-k2/mean));
chi+=Math.pow(fr[i]/pp,2)/pp; }
System.out.println("Exponential distribution lamda=+1.0/mean");
k1=20.09;
coincidence(ty, k1, chi);
//powerDistr(v, deg); 

public static void coincidence(int ty, double k1, double ss) {
    if (ss<=k1)
    if (ss>=0) {
        if (ty==1) System.out.println("Degrees are binomially distributed.");
        if (ty==2) System.out.println("Degrees are Poisson distributed.");
        if (ty==3) System.out.println("Degrees are exponentially distributed.");
        if (ty==1) System.out.println("It is a random network");
        if ((ss<k1) & (ty==1) | (ty==2)) System.out.println("It is likely not a random network");
        if ((ss<k1) & (ty==3)) System.out.println("It is not an exponential network");
    }
    public static void powerDistr(int v, int x[])) {
    //Power law distri., f(x)=x^α
    int i,j,k,n,r,xmin;
    double xmax,a,alpha,dd,maa;
    int xmin[1][v+1];
    double z[1][v+1];
    double x[1][v+1];
    double xmin[1][v+1];
    double c[1][v+1];
    double dat[1][v+1];
    k=1;
    xmin[1][0]=x[1];
    for(i=1;i<=v;i++) {
        n=0;
        for(j=1;j<=k;j++)
            if (x[i]!=xmin[j]) n++;
        if (n==k) 
            k++;
        xmin[i][k]=x[i];
    }
    for(i=1;i<=v;i++)
        for(j=1;j<=k;j++)
            if (x[j]>=xmin[i]) n++;
    maa=0;
    for(i=1;i<=v;i++)
        if (dat[i]<=dd) dd=dat[i];
    for(i=1;i<=v;i++)
        if (dat[i]>=dd) {
            k=i;
            for(j=1;j<=v;j++)
                if (x[j]>=xmin[i]) n++;
            maa=0;
            for(i=1;i<=v;i++)
                if (dat[i]<=dd) maa+=Math.log(zz[i]/xmin);
            a=n/maa;
            for(i=1;i<=v;i++)
                if (i<n) c[i]=1-Math.pow(xmin[1][i],a);
            dat[r]=0;
            for(i=1;i<=v;i++)
                if (dat[i]<dd) dd=dat[i];
            for(i=1;i<=v;i++)
                if (dat[i]>=dd) {
                    k=i;
                    break;
                }
            xmin=xmins[k];
        }
    }
for(i=1;i<=n;i++) maaa+=Math.log(zz[i]/xmin);
alpha=1+n/maaa;
alpha=(n-1)*alpha/n+1.0/n;
System.out.println("Power law distribution KS D value="+dd);
if (dd<(1.63/Math.sqrt(n))) System.out.println("Degrees are power law distributed, it is a scale-free complex network");
System.out.println("Power law alpha="+alpha);
System.out.println("Power law xmin="+xmin);
}

2.2 Data source

Interaction Web Database (National Center for Ecological Analysis and Synthesis, 2011; http://www.nceas.ucsb.edu/interactionweb/) was chosen as the data source of the present study. Interaction Web Database contains seven food webs, namely Anemone-Fish, Host-Parasite, Plant-Ant, Plant-Herbivore, Plant-Pollinator, Plant-Seed disperser, and Predator-Prey sub-webs. For each web, the species with corresponding intraspecific relationship but not all species in the ecosystem or community, were included. Each of seven food webs was used to calculate degree distribution and detect network type.

For Anemone-Fish web, we used the data of Fautin and Allen (1997) and Ollerton et al. (2007), as indicated in Table 3. The data for other webs were chosen as follows:

Host-Parasite webs: we used the data for Canadian freshwater fish and their parasites (Arthur et al., 1976), which were from the investigation to seven water systems. Moreover, the data from Cold Lake (Leong et al., 1981; 10 hosts and 40 parasites) and Parsnip River (Arai et al., 1983; 17 hosts and 53 parasites) were also used.

Plant-Ant web: the data of Bluthgen (2004) from tropical rain forests, Australia, were used. There were 51 plants and 41 ants in this web.

Plant-Herbivore web: the data from Texas, USA (Joern, 1979; 54 plants and 24 herbivores) were used.

Predator-Prey webs: four sets of data (Berwick, Catlins, Coweeta and Venlaw) were used. The major species included algae, fish, arthropods and amphibians. Patient-Seed disperser webs: two sets of data were used. One from a forest in Papua New Guinea (Beehler, 1983; 31 plants and 9 birds), and one from a tropical forest in Panama (Poulin et al., 1999; 13 plants and 11 birds).

A typical raw data in Interaction Web Database is indicated in Table 1.

| Table 1 An example of the data of Interaction Web Database. |
|--------------------------|----------------------|----------------------|----------------------|
| Species                  | Unidentified detritus | Terrestrial invertebrates | Plant material |
| Unidentified detritus    | 0                    | 0                     | 0                     |
| Terrestrial invertebrates| 0                    | 0                     | 1                     |
| Plant material           | 0                    | 1                     | 0                     |
| Achnanthes lanceolata    | 0                    | 0                     | 0                     |

General information In this paper, the authors examined the feeding patterns of grasshoppers from two arid grassland communities in Trans-Pecos, Texas. The studies took place from May until November in 1974 and 1975.

Date type The authors recorded the identities of insect and plant species and their interactions. Data are presented as a binary interaction matrix, in which cells with a "1" indicate an interaction between a pair of species, and a "0" indicates no interaction.
In Table 1, the values 1 and 0 represent having or not having interspecific trophic relationship. The values neither 1 nor 0 represent frequencies and these values were transformed to 1 in present study. Table 1 should be transformed to the format needed by the Java algorithm above, as indicated in Table 2.

### Table 2
The data transformed from Table 1.

<table>
<thead>
<tr>
<th>ID of Taxon 1</th>
<th>ID of Taxon 2</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>1</td>
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<tr>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

### 3 Results
The data of Anemone-Fish web is indicated in Table 3.

### Table 3
Species and ID of Anemone-Fish web.

<table>
<thead>
<tr>
<th>Genera</th>
<th>Species</th>
<th>ID</th>
<th>Genera</th>
<th>Species</th>
<th>ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphiprion spp.</td>
<td>Akallolposis</td>
<td>1</td>
<td>Amphiprion spp.</td>
<td>percula</td>
<td>19</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>Akindynos</td>
<td>2</td>
<td>Amphiprion spp.</td>
<td>perideraion</td>
<td>20</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>Allardi</td>
<td>3</td>
<td>Amphiprion spp.</td>
<td>polymnus</td>
<td>21</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>Bicinctus</td>
<td>4</td>
<td>Amphiprion spp.</td>
<td>rubrocinctus</td>
<td>22</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>chrysogaster</td>
<td>5</td>
<td>Amphiprion spp.</td>
<td>sandaracinos</td>
<td>23</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>chrysopterus</td>
<td>6</td>
<td>Amphiprion spp.</td>
<td>sebae</td>
<td>24</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>clarkii</td>
<td>7</td>
<td>Amphiprion spp.</td>
<td>tricinctus</td>
<td>25</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>ephippium</td>
<td>8</td>
<td>Premnas</td>
<td>biauleatus</td>
<td>26</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>frenatus</td>
<td>9</td>
<td>Heteractis</td>
<td>crispa</td>
<td>27</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>fuscocaudatus</td>
<td>10</td>
<td>Entacmaea</td>
<td>quadricolor</td>
<td>28</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>latezonatus</td>
<td>11</td>
<td>Heteractis</td>
<td>magnifica</td>
<td>29</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>latifasciatus</td>
<td>12</td>
<td>Stichodactyla</td>
<td>mertensi</td>
<td>30</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>leucokranos</td>
<td>13</td>
<td>Heteractis</td>
<td>aurora</td>
<td>31</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>mccullochi</td>
<td>14</td>
<td>Stichodactyla</td>
<td>gigantea</td>
<td>32</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>melanopus</td>
<td>15</td>
<td>Stichodactyla</td>
<td>haddoni</td>
<td>33</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>nigipes</td>
<td>16</td>
<td>Macrodictyla</td>
<td>doreensis</td>
<td>34</td>
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<tr>
<td>Amphiprion spp.</td>
<td>ocellaris</td>
<td>17</td>
<td>Heteractus</td>
<td>malu</td>
<td>35</td>
</tr>
<tr>
<td>Amphiprion spp.</td>
<td>omanensis</td>
<td>18</td>
<td>Cryptodendrum</td>
<td>adhaesivum</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 3 is transformed to the data type needed by the Java algorithm, as indicated in Table 4.
Table 4 A data type of Anemone-Fish web.

<table>
<thead>
<tr>
<th>ID of taxon 1</th>
<th>ID of taxon 2</th>
<th>Value</th>
<th>ID of taxon 1</th>
<th>ID of taxon 2</th>
<th>Value</th>
</tr>
</thead>
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</table>

Some results running the Java algorithm for Anemone-Fish web are as follows:

- Skewness of degree distribution: 0.2739383901373063
- Aggregation index of the network: 1.519811320754717
- It is a complex network.
- Variation coefficient H of the network: 3.361428571428571
- It is a complex network.
- Binomial distribution Chi-square=84779.33198479559
- Binomial p=0.2222222222222222
- It is likely not a random network
- Poisson distribution chi-square=462.75941519476396
- Poisson lamda=4.444444444444445
- It is likely not a random network
Exponential distribution $\lambda=0.2249$  
Degrees are exponentially distributed.  
Power law distribution KS D value=0.0  
Degrees are power law distributed, it is a scale-free complex network  
Power law alpha=NaN  
Power law xmin=14

It is obvious that the food web is a complex network.  
The results for all food webs are listed in Table 5 and 6.

**Table 5** Summary of results for calculation of degree distribution and network type.

<table>
<thead>
<tr>
<th>Data source</th>
<th>Anemone-Fish web</th>
<th>Host-Parasite webs</th>
<th>Plant-Ant web</th>
<th>Plant-Pollinator webs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skewness of degree distribution</td>
<td>0.2739</td>
<td>0.2524</td>
<td>0.2822</td>
<td>0.2404</td>
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<tr>
<td>Aggregation index of the network</td>
<td>1.5198</td>
<td>1.6913</td>
<td>1.7425</td>
<td>1.6709</td>
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<td>Variation coefficient of the network</td>
<td>3.3614</td>
<td>4.0615</td>
<td>3.7425</td>
<td>4.0627</td>
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<tr>
<td>Binomial distribution Chi-square</td>
<td>84779.33</td>
<td>316459.4</td>
<td>1500517</td>
<td>53631.9</td>
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<td>Binomial p</td>
<td>0.2222</td>
<td>0.2099</td>
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<td>0.1905</td>
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<tr>
<td>Poisson distribution Chi-square</td>
<td>462.759415</td>
<td>538.79</td>
<td>498.22</td>
<td>1661.19</td>
</tr>
<tr>
<td>Exponential distribution lamda</td>
<td>0.2249</td>
<td>0.2308</td>
<td>0.2747</td>
<td>0.2215</td>
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<tr>
<td>Power law distribution KS D value</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Power law alpha</td>
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<td>-</td>
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<tr>
<td>Power law Xmin</td>
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<tr>
<td>Type of degree distribution</td>
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<td>Power law</td>
<td>Power law</td>
<td>Power law</td>
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<tr>
<td>Network type</td>
<td>Complex network</td>
<td>Complex network</td>
<td>Complex network</td>
<td>Complex network</td>
</tr>
</tbody>
</table>

From variation coefficient and aggregation index in Table 5 and 6, we can find that all values are greater than 1 and all webs are thus complex networks. Plant-Pollinator web (Ollerton et al, 2003) is the most complex, seconded by Predator-prey web (Catlins) and Plant-Ant web (Bluthgen, 2004), the complexity of Plant-Seed disperser web (Poulin, 1999) is the lowest. It can be fond that the skewness of Plant-Pollinator web (Ollerton et al, 2003) is the smallest and its degree distribution is the most skewed, which reveals it is the most complex network.

The results show that the degree distribution of most of the food webs is power law and exponential distribution, and all of the food webs are complex networks.
### Table 6 Summary of results for calculation of degree distribution and network type.

<table>
<thead>
<tr>
<th></th>
<th>P-H web</th>
<th>Plant-Seed disperser webs</th>
<th>Predator-Prey webs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data source</td>
<td>Joern, 1979</td>
<td>Veehler 1983</td>
<td>Poulin, 1999</td>
</tr>
<tr>
<td>Skewness of degree distribution</td>
<td>0.2261</td>
<td>0.1969</td>
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<td>Aggregation index of the network</td>
<td>1.8139</td>
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<td>1.2334</td>
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<tr>
<td>Variation coefficient H of the network</td>
<td>4.6468</td>
<td>4.8003</td>
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<tr>
<td>Binomial distribution Chi-square</td>
<td>48066.1</td>
<td>1451.8</td>
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<tr>
<td>Binomial p</td>
<td>0.1182</td>
<td>0.2</td>
<td>0.3333</td>
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<td>Poisson distribution Chi-square</td>
<td>2167.1</td>
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<td>Poisson lambda</td>
<td>4.4359</td>
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<td>Exponential distribution lambda</td>
<td>0.2254</td>
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<td>D value</td>
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<td>Power law Xmin</td>
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<tr>
<td>Network type</td>
<td>Complex network</td>
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</tr>
</tbody>
</table>

Note: P-H web means Plant-Herbivore web.

### 4 Discussion

Different from classical distribution patterns (bionomial distri., Poisson distri., and power law distri., etc.), both network type and network complexity can be calculated and compared using the indices above, i.e., aggregation index, coefficient of variation, skewness, etc. We suggest they should be used in the network analysis.

Other indices to detect aggregation strength can also be used in network analysis. For example, the Lloyd index:

\[
L = 1 + (s^2 - \bar{u})/\bar{u}^2,
\]

where \(\bar{u}, s^2\): mean and variance of network degree. The network is a random network, if \(L \leq 1\). It is a complex network, if \(L > 1\), and network complexity increases with \(L\). It is obvious that at certain extent the entropy \(E\), defined above, is equivalent to \(L\).
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Gonenc IE, Koutitsky VG, Rashleigh B. 2007. Assessment of the Fate and Effects of Toxic Agents on Water Resources. Springer


Zhang WJ. 2007. Methodology on Ecology Research. Sun Yat-sen University, Guangzhou, China