**Doc.2. AWI April 2012**

**Guidelines for the use of NETWRK4.2**

**I. Introduction**

Sometime during the mid-1970's it became apparent that

ecological modelling in the form of a set of coupled, deterministic

differential equations was not going to be the panacea for analyzing whole

ecosystems. In the search for alternative methods of describing the

behaviour of total ecosystems, various computations performed on the

underlying network of flows have figured prominently (SCOR, 1981).

The original impetus for confining analysis to flow structure

came from the field of economics, where success in elucidating indirect

economic effects had been achieved by manipulations on matrices of

economic flows (Leontief, 1959; Hannon, 1973). Thereafter followed a

number of other topological treatments of the underlying flow graph (e.g.,

Finn, 1976; Levine, 1980; Patten et al., 1976; Ulanowicz and Kemp, 1979).

Subroutines has been written by Bob Ulanowicz to collect the various

algorithms into a single large program which allows an investigator to

choose that analysis which best serves his needs.

Four types of analyses are performed by this routine. The

outputs are presented in ascending degree of network aggregation.

* First, input-output structure matrices are calculated, allowing one to

look in detail at the effects any particular flow or transformation

might have on any other given species or flow.

* Next, the network graph is mapped into a concatenated trophic chain

(after Lindeman).

* Then all the simple, directed biogeochemical cycles are identified and

separated from their supporting dissipative flows.

* Finally, global variables describing the state of development of the

network, and other functional indices are presented.

The documentation of the package follows in two sections.

***First***, a description of the data requirements and input format necessary

to run the program is given. This is the minimum one needs to know to run the

package.

***Secondly***, a brief description of the meaning of the outputs with appropriate

references to aid in a more thorough understanding of the technique.

**II. Necessary Input**

All of the routines contained herein require data on the entire

network of exchanges of a particular medium (energy, Carbon, or any other

element). Sometime prior to data collection assumptions had to have

been made on how the ecosystem (or other system) was to be aggregated into

compartments. For each compartment it is necessary to know:

(1) all the inputs (imports) from outside the system,

(2) all the various inputs flowing from other compartments of the system,

(3) all the outputs which flow as inputs to other compartments,

(4) all exports to outside the system, and

(5) all rates of dissipation of energy or another medium.

The system need not to be at steady-state (when the sum of all the inputs to

each compartment is balanced by the sum of all the outputs from the same

compartment), although a diagnostic warning will be printed whenever any

compartment does not balance. The absence of a flow is represented by a zero.

Negative magnitudes of flow are forbidden in the software routines and should be recast as positive quantities. The distinction between useful exports and dissipated respirations

is, unfortunately, not made by some authors and collectors of data. As can be

seen from the results, this distinction is an important one and should be made

wherever possible.

A sample of a simple energy flow network of a Simple6 hypothetical system is given

below in Fig. 1.

***FIG 1.***

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Ecosystem Simple6. Biomass in mgCm-2, flows in mgCm-2-2day-1.

***Input file: Simple6\_Dat.txt***

***Table 1***

***Ecosystem Simple6.***

***6 5***

***Phytoplankton***

***Zooplankton***

***Suspension feeder***

***Fish X***

***Bird Y***

***Suspended POC***

***1 .5000000E+02***

***2 .3000000E+02***

***3 .1000000E+02***

***4 .2000000E+01***

***5 .1000000E+01***

***6 .1000000E+02***

***-1 .0000000E+00***

***1 .1000000E+03***

***6 .1900000E+02***

***-1 .0000000E+00***

***2 .1200000E+02***

***4 .2000000E+01***

***5 .1000000E+01***

***-1 .0000000E+00***

***1 .4000000E+02***

***2 .2500000E+02***

***3 .3000000E+02***

***4 .1000000E+01***

***5 .8000000E+01***

***-1 .0000000E+00***

***1 2 .2000000E+02***

***1 3 .3000000E+02***

***1 6 .1000000E+02***

***2 4 .4000000E+01***

***2 5 .4000000E+01***

***2 6 .5000000E+01***

***3 5 .1000000E+02***

***3 6 .1000000E+02***

***4 6 .1000000E+01***

***5 6 .5000000E+01***

***6 2 .3000000E+02***

***6 3 .2000000E+02***

***-1 -1 .0000000E+00***

The first record is a header or title which serves to identify

the data and the resultant output. It is passed on as 78 characters of

alpha-numeric data to the output file. It may contain any

information the user desires. In this instance a descriptive title, a

citation for the data source, and the units of the flows can be entered in the

heading.

The first entry on the second record is the number of compartments in the network.

Call this value N. Practically everything else is dimensioned by N. In the above example there are **6** compartments, followed by citing the number of living compartments...namely **5.**

The network dimension record is followed by N records of alphanumeric titles,

each title describing its respective compartment. Compartment descriptors

may be up to 25 characters long and are simply transcribed onto the output file

for easy reference in interpreting the printout of results.

The ordering of the compartments should be such that the living populations

appear first and the non-living compartments are grouped at the end.

The last compartment name precedes a series of values for the **biomass** of each

component. Each record consists of an integer compartment number followed by the

value of the stock. **After the last biomass has been entered, the end of the series**

**is denoted by a negative integer [-1] in the first three spaces**.

The biomasses are followed by the inputs, and the inputs by the

exports. Each separated from the other by a negative integer **-1**

The fourth series consists of respirations. As with the biomasses, the end

is signified by a negative value [-1].

The fifth series gives the flows from prey to predator [i to j]. Here two

integers are used to define the donor [i] and recipient compartments [j] of each

exchange. The end of the exchanges is denoted by a record with a negative

integer [-1]. Each given exchange will appear in the exchange matrix so that the j-th

element of row i represents the flow originating from compartment i and

terminating in compartment j.

All flow values must be non-negative, or else a diagnostic and

termination of the run will result.

**III. Output of Results**

**SEE TABLE 2 BELOW**

The output resulting from the sample input file is listed at the

end of this section. It is divided into five segments.

The **initial** segment begins with echos of the input data, the

header record, the total number of compartments, the number of living

compartments, the names of the various compartments both living and non-

living, the input vector, export vector, respiration vector and matrix of

exchanges. The throughput of a compartment is the total amount of medium

flowing through that compartment. In input-output analysis it is a

measure of the importance of that particular entity. The sum of these

throughputs is called the **Total System Throughput [TST].** It is a flow measure

of the total system size and activity.

The **second** section of output presents an ecological variation of

**input-output analysis**. The **total contribution** coefficients describe

exactly what fraction of the total amount leaving compartment i (row

designation) eventually enters compartment j (column designation) over all

real pathways, direct and indirect. For example, of all the gross

production by compartment 1 (phytoplankton), about 2.82% eventually enters

compartment 4 [Fish X]. More interestingly, 16.8% of the gross

fish production winds up in zooplankton [the 4i-2j entry].

The rows of the contribution matrix usually sum to more than one,

because output from a given compartment can visit several other

compartments before exiting the system. Each diagonal entry indicates how

much self-stimulation is being effected by that particular compartment.

The **total dependency** coefficients portray the inverse to the

perspective afforded by the previous matrix. Namely, the i-jth entry is

the fraction of the total ingestion by j which passed through compartment

i along its way to j. Hence, about 17.9% of the fish diet (4) was mediated

by the suspension feeder [3]. The columns of this matrix are particularly

useful in that they portray the extended diet of the species in question.

Thus, although the fish [4] receive direct sustenance only from zooplankton

[2], we see from column 4 in the dependency matrix that the

fish obtain 71.6% of their energy uptake ultimately from the plants, 100% from

zooplankton [2], 17.9% from suspension feeders [3], 1.47% from

its own output [through cycling], 7.08% from birds [5]and 60% from Suspended

POC [6]. Such indirect rations should provide valuable information to those

managing a particular species.

The **third** section interprets the given network according to the

**trophic concepts of Lindeman** (1942). Of course, it is impossible to

relegate many heterotrophs entirely to a single trophic level, but

Ulanowicz and Kemp (1979) indicated how input-output techniques could be

used to **apportion the activities of omnivores among a series of integer**

**trophic levels**. This method has been expanded to include the effects of

biogeochemical cycles by Ulanowicz (1987), and it is that formulation

which is implemented in this section.

In order for the results of this section to be meaningful, it

was necessary to have specified the number of compartments that represent

living populations, say NL ( < N ), and to have ordered the species so

that the N-NL abiotic compartments appeared last in the series. The

trophic aggregation algorithm also requires that no cycles appear entirely

among the living compartments.

If the number of living compartments (NL) is not given in the

input, then a default value of N is assumed, i.e., everything is alive.

In this event, all the cycles will be removed, and the entire trophic

analysis will be conducted on the acyclic residual network. Thus it is

essential to make the distinction between living and abiotic compartments!

The first item to appear in this section is the Lindeman

transformation matrix. It has dimension NL x NL and may contain rows of

zeros towards the bottom of the matrix. Its columns represent the

apportionment of the corresponding species among the integer trophic

levels. Hence, the birds have been assigned 100% to

trophic level 3. The columns of this matrix should

always sum to one. Reading across a row gives the composition of a

trophic level. All abiotic activity is condensed into the Nth compartment

and assigned a trophic level of one. [See “Effective trophic level of each species”].

When the figures in each column of the transformation matrix are

weighted by the value of the trophic level and the results are summed, one

arrives at the effective trophic level for that species. These trophic

position values have been defined by Levine (1980) as a measure of the

average trophic level at which the compartment is receiving medium. For

example, if a species or compartment is receiving 15 units of medium along

a pathway of length 2 and 5 units along a pathway of length 3, then it is

acting 75% as a herbivore (trophic level=2) and 25% as a carnivore

(level=3). The effective trophic position becomes (.75 x 2)+(.25 x

3)=1.75. The average trophic levels in the Simple6 Ecosystem network are rather

unexciting, but the same analysis on more complex networks often yields

interesting surprises.

The "canonical" exports and respirations are the amounts leaving

the system from the integer trophic levels. Again, the Nth or last

compartment represents the aggregated Suspended POC pool. The elements of the

grazing chain represent the inputs to each integer trophic level from the

preceding level. (The first value is the aggregate of the exogenous

inputs. The second entry represents herbivorous grazing.

The returns from each level of the trophic chain to the detrital pool are

listed in the next vector. Detritivory refers to the flow from the detrital pool to the second

trophic level. “Detrivory” gives the amount of Suspended POC that enters [or flows to]

the second trophic level.

The exogenous inputs to the detrital pool total 9 units in Simple6,

and there is no internal circulation within the pool. (Any

positive value here would be represented by a "self loop" on the detrital

compartment.) The configuration of the data presented thus far can be

depicted as in ***Fig. 2***.

When the detrital pool is merged with the autotrophs, the resultant

"Lindeman spine" necessarily will form a decreasing sequence of flows. One

can speak of trophic efficiency as the ratio of the input to a trophic

level to the amount that level passes on to the next. Thus, of the 100

units entering level 2, only 18 are passed on to level 3, a 16.4% trophic

efficiency. The trophic representation of Simple6 after the merger of

the autotrophs with the detrital pool is shown in ***Fig. 3***.



The **final** short segment of output provides values for global

attributes of the network as defined by Ulanowicz (1980,1986) Hirata

and Ulanowicz (1984), Ulanowicz and Norden (1988).

The **total system throughput** has already been defined and serves

as a measure of the size of the system. Multi-plying the total throughput

by the entropy (according to the Shannon-Wiener formula) of the

individual flows yields the **development capacity**.

This quantity is an upper bound on the **ascendency**, a measure of the

network's potential for growth and its competitive advantage over other real or putative

network configurations. Ascendency is the product of a factor of size

(total system throughput) times a factor representing the coherence of

the flows (the average mutual information of the flow structure.)

The difference between the realized structure and its upper

bound is the **overhead** (Ulanowicz, 1988) and consists of four components

-- there is overhead due to uncertainty about **imports**, **exports**

and **dissipations** (respirations), and the flows that are proceeding

along parallel pathways (**redundancy**.) The fractions of the

development capacity devoted to each of its five components are given

in parentheses following the values. A few connectance indices are also

from these analyses.

The foregoing indices were descriptors of the entire system.

Ulanowicz (1986; also Hirata and Ulanowicz, 1984) shows how growth and

development in networks are best characterized by components of the

internal capacity (as calculated over only internal exchanges.) There

are two -- the internal ascendency and the internal redundancy. A few

connectance indices are also given.

***Table 2***

***Ecosystem Simple6.***

***NUMBER OF COMPARTMENTS IS 6***

***NUMBER OF LIVING COMPARTMENTS IS 5***

***LIVING COMPARTMENTS***

***1 Phytoplankton***

***2 Zooplankton***

***3 Suspension feeder***

***4 Fish X***

***5 Bird Y***

***NON-LIVING COMPARTMENTS***

***6 Suspended POC***

***INPUT VECTOR***

***1 2 3 4 5 6***

***.100E+03 .000E+00 .000E+00 .000E+00 .000E+00 .190E+02***

***EXPORT VECTOR***

***1 2 3 4 5 6***

***.000E+00 .120E+02 .000E+00 .200E+01 .100E+01 .000E+00***

***RESPIRATION VECTOR***

***1 2 3 4 5 6***

***.400E+02 .250E+02 .300E+02 .100E+01 .800E+01 .000E+00***

***EXCHANGE MATRIX***

***1 2 3 4 5 6***

***1 .000E+00 .200E+02 .300E+02 .000E+00 .000E+00 .100E+02***

***2 .000E+00 .000E+00 .000E+00 .400E+01 .400E+01 .500E+01***

***3 .000E+00 .000E+00 .000E+00 .000E+00 .100E+02 .100E+02***

***4 .000E+00 .000E+00 .000E+00 .000E+00 .000E+00 .100E+01***

***5 .000E+00 .000E+00 .000E+00 .000E+00 .000E+00 .500E+01***

***6 .000E+00 .300E+02 .200E+02 .000E+00 .000E+00 .000E+00***

***COMPARTMENTAL THROUGHPUTS***

***1 2 3 4 5 6***

***.100E+03 .500E+02 .500E+02 .400E+01 .140E+02 .500E+02***

***\*\*\* STRUCTURE ANALYSES \*\*\****

***TOTAL CONTRIBUTION COEFFICIENTS***

***1 2 3 4 5 6***

***1 .000E+00 .322E+00 .357E+00 .282E-01 .104E+00 .211E+00***

***2 .000E+00 .100E+00 .652E-01 .876E-01 .981E-01 .149E+00***

***3 .000E+00 .183E+00 .119E+00 .160E-01 .230E+00 .271E+00***

***4 .000E+00 .168E+00 .110E+00 .147E-01 .377E-01 .250E+00***

***5 .000E+00 .240E+00 .157E+00 .211E-01 .539E-01 .357E+00***

***6 .000E+00 .673E+00 .439E+00 .589E-01 .151E+00 .198E+00***

***TOTAL DEPENDENCY COEFFICIENTS***

***1 2 3 4 5 6***

***1 .000E+00 .716E+00 .811E+00 .716E+00 .783E+00 .526E+00***

***2 .000E+00 .100E+00 .667E-01 .100E+01 .333E+00 .167E+00***

***3 .000E+00 .179E+00 .119E+00 .179E+00 .765E+00 .298E+00***

***4 .000E+00 .147E-01 .982E-02 .147E-01 .112E-01 .246E-01***

***5 .000E+00 .708E-01 .472E-01 .708E-01 .539E-01 .118E+00***

***6 .000E+00 .600E+00 .400E+00 .600E+00 .457E+00 .198E+00***

***EFFECTIVE TROPHIC LEVELS OF EACH SPECIES***

***1 2 3 4 5 6***

***.100E+01 .200E+01 .200E+01 .300E+01 .300E+01 .100E+01***

***CANONICAL EXPORTS***

***1 2 3 4 5 6***

***.000E+00 .120E+02 .300E+01 .000E+00 .000E+00 .000E+00***

***CANONICAL RESPIRATIONS***

***1 2 3 4 5 6***

***.400E+02 .550E+02 .900E+01 .000E+00 .000E+00 .000E+00***

***THE GRAZING CHAIN***

***1 2 3 4 5***

***.100E+03 .500E+02 .180E+02 .000E+00 .000E+00***

***RETURNS TO DETRITAL POOL***

***1 2 3 4 5***

***.100E+02 .150E+02 .600E+01 .000E+00 .000E+00***

***DETRITIVORY = .50000E+02***

***INPUT TO DETRITAL POOL = .19000E+02***

***CIRCULATION WITHIN DETRITAL POOL = .00000E+00***

***LINDEMAN SPINE***

***1 2 3 4 5***

***.140E+03 .100E+03 .180E+02 .000E+00 .000E+00***

***TROPHIC EFFICIENCIES***

***1 2 3 4***

***.714E+00 .180E+00 .000E+00 .000E+00***

***\*\*\* INFORMATION INDICIES \*\*\****

***TOTAL SYSTEM THROUGHPUT = .38700E+03***

***DEVELOPMENT CAPACITY = .14303E+04***

***ASCENDENCY = .50272E+03 (.351)***

***OVERHEAD ON IMPORTS = .10191E+03 (.071)***

***OVERHEAD ON EXPORTS = .44098E+02 (.031)***

***DISSIPATIVE OVERHEAD = .30511E+03 (.213)***

***REDUNDANCY = .47642E+03 (.333)***

***INTERNAL CAPACITY = .67466E+03***

***INTERNAL ASCENDENCY = .19824E+03 (.294)***

***REDUNDANCY = .47642E+03 (.706)***

***\*\*\* CONNECTANCE INDICES \*\*\****

***OVERALL CONNECTANCE = 2.061***

***INTERCOMPERTMENTAL CONNECTANCE = 2.256***

***FOODWEB CONNECTANCE = 1.419***

***\*\*\* FULL CYCLE ANALYSIS \*\*\****

***1-CYCLE NEXUS WITH WEAK ARC ( 4, 6) = .1000E+01***

***1. 4- 6- 2- 4-***

***1-CYCLE NEXUS WITH WEAK ARC ( 2, 5) = .4000E+01***

***2. 2- 5- 6- 2-***

***1-CYCLE NEXUS WITH WEAK ARC ( 5, 6) = .5000E+01***

***3. 5- 6- 3- 5-***

***1-CYCLE NEXUS WITH WEAK ARC ( 2, 6) = .5000E+01***

***4. 2- 6- 2-***

***1-CYCLE NEXUS WITH WEAK ARC ( 3, 6) = .1000E+02***

***5. 3- 6- 3-***

***A TOTAL OF 5 CYCLES REMOVED.***

***CYCLE DISTRIBUTIONS***

***1 2 3 4 5 6***

***.000E+00 .300E+02 .180E+02 .000E+00 .000E+00 .000E+00***

***NORMALIZED DISTRIBUTION***

***1 2 3 4 5 6***

***.000E+00 .775E-01 .465E-01 .000E+00 .000E+00 .000E+00***

***FINN CYCLING INDEX IS .1240E+00***

Most ecosystem graphs contain biogeochemical cycles of material

or energy, and the structure of these cycles is fully described by the

fourth section of the output. First to appear is an enumeration of all

the simple cycles in the given exchange matrix (only 5 in this case).

Furthermore, the simple cycles are grouped into "nexuses" of cycles which

share the same "weak arc." A weak arc is defined here as the smallest flow

in a given directed cycle. The assumption is that the weak arc is the

limiting or controlling link in a cycle, and that by grouping according to

weak arc, one defines the domain of influence of each weak arc.

Presumably, a change in any weak arc flow will propagate throughout the

associated nexus. The nexuses are always listed in ascending order of the

magnitude of the weak arc (the identity and magnitude of which is printed

as a header to each nexus). The order of the cycles within any nexus is

of no particular significance, but corresponds to the order in which the

cycles were identified by the routine CYCLES. The number of cycles in the

sample network is quite sparse, and the grouping by weak arc is almost

trivial. However, the user will soon discover that in networks of only

slightly more complexity the total number of cycles mushrooms, and the

number of cycles in a typical nexus increases accordingly.

This cycle distribution array shows how much flow is cycling in loops of

various sizes. Such a profile might be useful in assessing system

response to perturbation; for example, where cycling via larger loops

might be more sensitive to disturbance. When the

cycle distribution is normalized by the total system throughput, the

result is the normalized distribution. Summing the normalized

distribution yields the **Finn Cycling Index**, (**FCI**), or the fraction of all the

flow in the system which is being cycled (Finn, 1976). In Simple6, the

FCI = 12.4%.

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Recommended reading

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