Water-land nexus relationships in socio-economic system

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CONTENTS

All the Procedures and Theories

Background

Water land circulation

- Along with the rapid urbanization, the expansion of metropolitan has resulted in severe coupled problems of water and land resources.
- The interaction between water-land resources is complex, which not only exists in natural system, but also in human dominated socio-economic system.
- The tracking of flows and pathways within the concerned system can facilitate the regulation of virtual water circulation, land footprint flows and the adjustment of the sectors' responsibilities.

Water land nexus

- The urban water and land resource utilization system is often viewed simply as a consumer, or as a consumption process.
- However, such human dominated water circulation and land utilization has an overlapping part between the natural and artificial water cycles, which could be better understood by analysis of function and structure and driving mechanisms in the context of "ecological network".

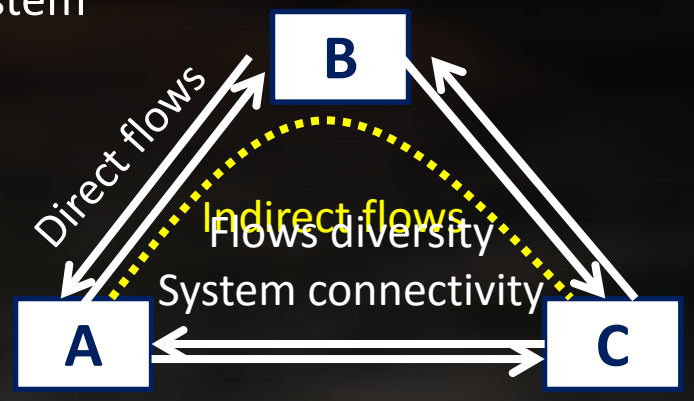
Background

Water - land network

- The systematic configuration of ***virtual water network (VWN)*** and ***embodied land network (ELN)*** should be explored to describe the network ***structures of inner interactions*** and ***distribution of water*** and ***land resources*** throughout the socio-economic system.
- The tracking of virtual water and embodied land fluxes and pathways within the system will facilitate the ***regulation of resources circulation*** and the adjustment of the ***sectors' responsibilities***.

Ecological network analysis

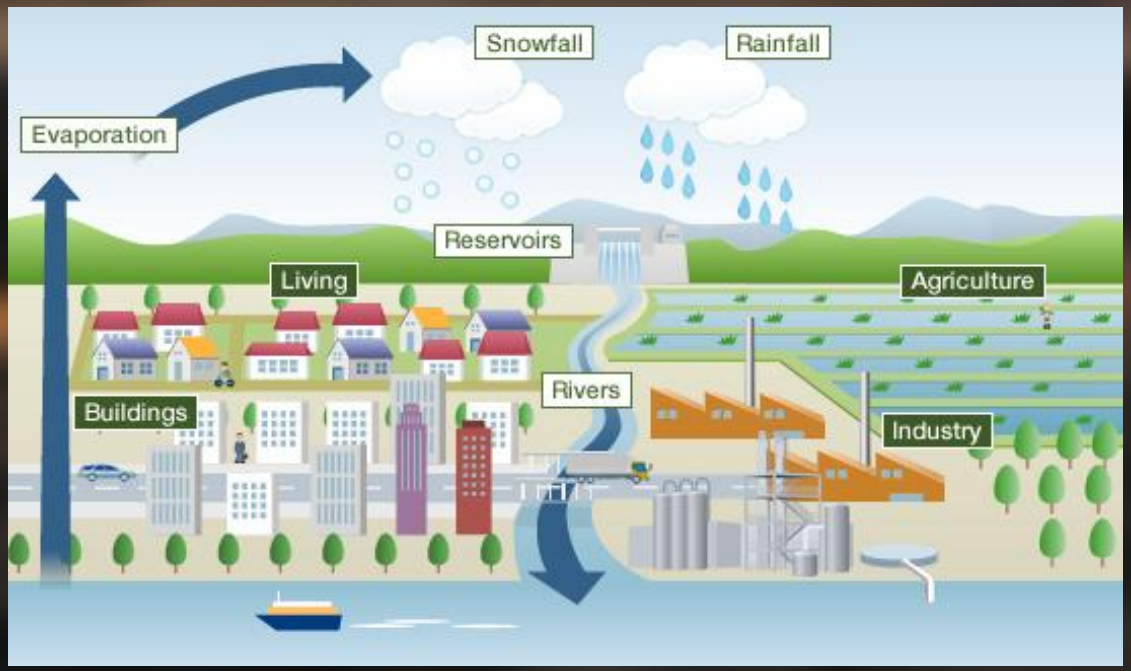
- Reveal ***indirect and cycling flows*** concealed in system
- Show the ***interdependence*** and ***interactions*** between different sectors
- Figure out the configuration of pathways ***diversity and connectivity***
- Discover ***robustness*** of the water system



Background

Water circulation

- Often viewed within the basic natural hydrologic.
- It has an overlapping part between the natural and artificial water cycles.
- Analysis of function and structure, socio-economic factors and driving mechanisms in the context of VWN.



Study Area

Heihe River

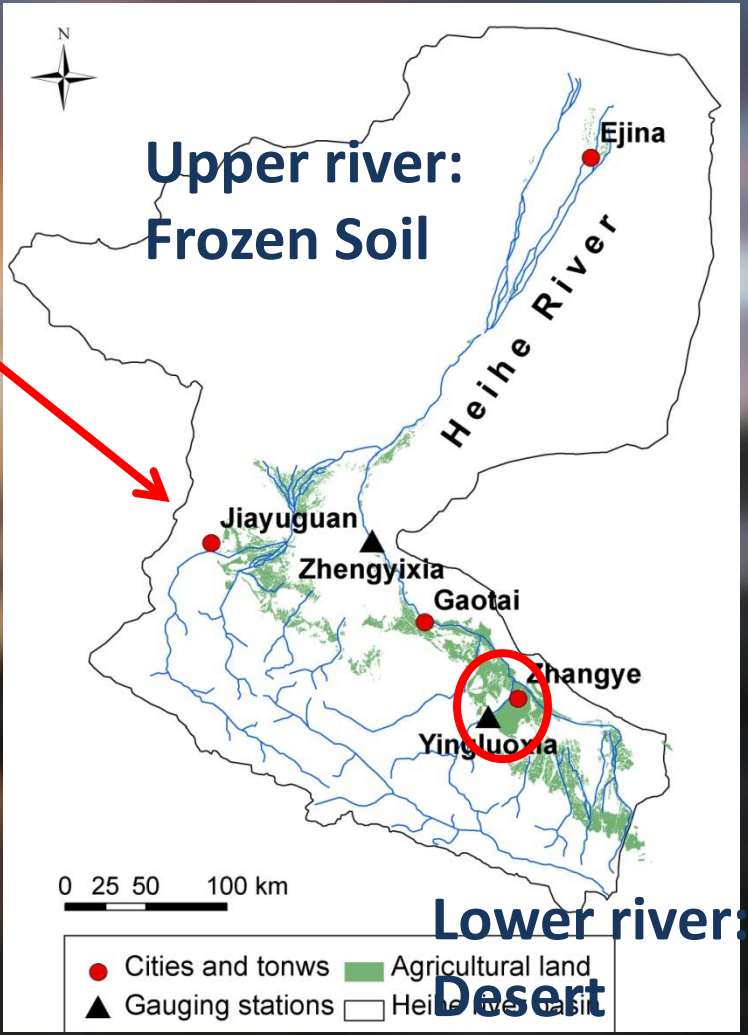
- The second largest inland river basin in arid Northwest China.

- Water resources: Limited but vital for development.

Ganzhou District

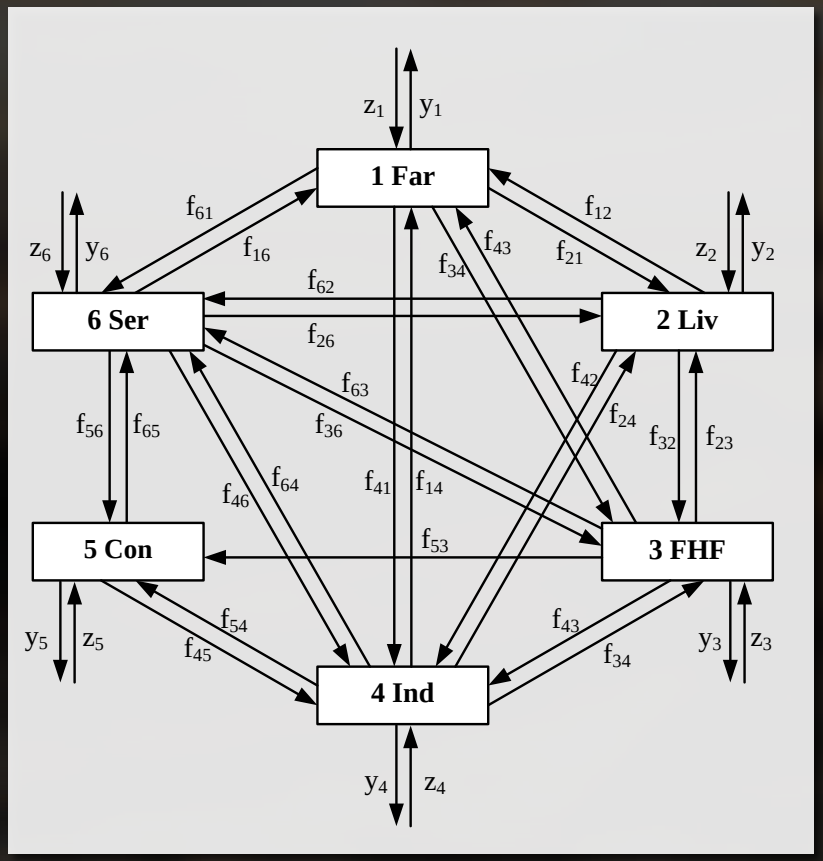
- One of the most economically developed regions in Heihe River Basin.
- Water consumption: Agricultural.

- ***Policies:***
  - Control total amount of water
  - Standard allocation of water in different regions
  - Reducing agricultural water consumption



Network construction

Network



Data source

- Gansu Statistical Yearbook 2012
- Zhangye Statistical Yearbook 2012
- Using environmental input-output model to establish the VWN.
- Each of the aggregated sectors consists of a block of sectors with ***similar water use habits***.
- To distinguish the ***pairwise relationship*** between ***similar sectors*** as a block and the other remaining blocks.

How to evaluate the **robustness** of the socio-economic network, and the **interaction** between pairwise sectors?

Size	Structure
Total volume water flow in the system	Configuration of flow, diversity and connectivity

A flow system's long-term Robustness depends on a judicious balance of ***Size*** and Internal ***Structure*** (Daly, 1997; Ulanowicz, 1980).

Ecological network indicators:

Throughflow
Cycling Index
Aggradation

Information-based network indicators:

Ascendency (efficiency)
Redundancy (resilience)
Development capacity (diversity)

Ecological network indicators

Flow intensity

$$g_{ij} = f_{ij} / T_j$$

Integral flow intensity

$$\mathbf{N} = \mathbf{G}^0 + \mathbf{G}^1 + \mathbf{G}^2 + \mathbf{G}^3 + \ldots + \mathbf{G}^m + \ldots = (\mathbf{I} - \mathbf{G})^{-1}$$

Throughflow

$$TST = M0 + M1 + M2$$

Total System throughflow	=	boundary flow	+	first passage flow	+	cycled flow

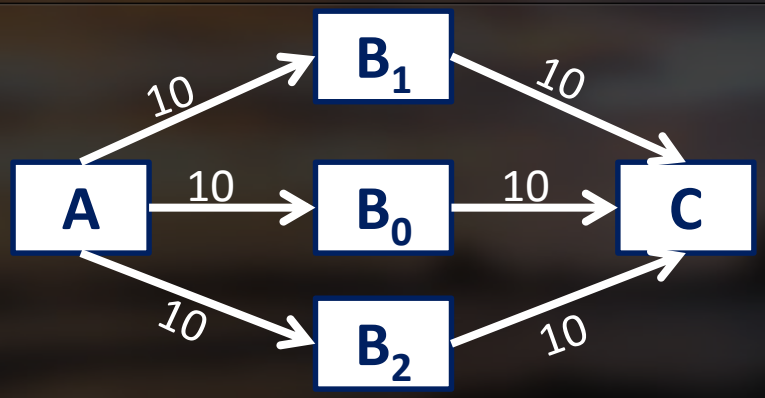
Information-based network indicators

Efficiency

Efficiency: Sufficient *directed power* to maintain its *integrity* over time.

System is regular and orderly, but less connected.

Resilience



Resilience: A reverse of *flexible actions* that can be used to meet the exigencies of novel disturbances

System is highly connected, but irregular and disorderly.

Information-based network indicators

Ascendency (*A*)

Average Mutual Information (*AMI*)

$$\mathrm{AMI} = K\sum_{i,j}\left(\frac{T_{ij}}{T_{..}}\right)\log\left(\frac{T_{ij}T_{..}}{T_{i.}T_{.j}}\right)$$

A = AMI × TST

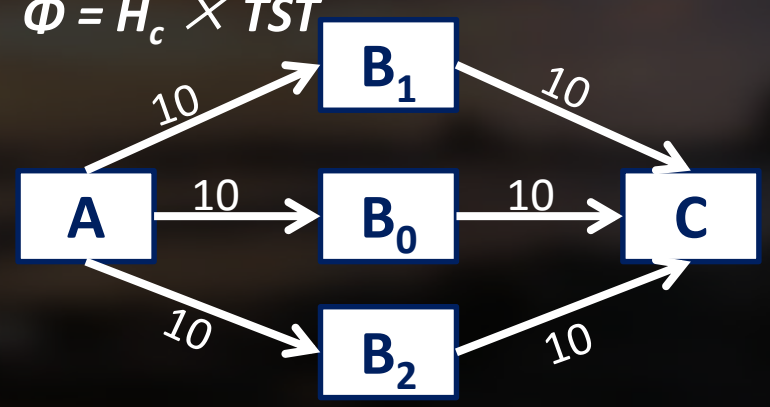
AMI **shows how well organized these flows are.**
E.g., a network <u>with *more flow along fewer links*</u> will have a higher *AMI*.

Redundancy (*Φ*)

Residual uncertainty (H_c)

$$H_c = -K\sum_{i,j}\left(\frac{T_{ij}}{T_{..}}\right)\log\left(\frac{T_{ij}^2}{T_{i.}T_{.j}}\right)$$

Φ = H_c × TST



H_c **shows the ability of system to withstand perturbations.**
E.g., a network with all flows <u>*equally distributed along all links*</u> will have a higher *H_c*.

Information-based network indicators

Ascendency (*A*)
Average Mutual Information (*AMI*)

Redundancy (*Φ*)
Residual uncertainty (H_c)

Development Capacity (*C*)
Flow diversity(*H*)

$$H = -K \sum_{i,j} \left(\frac{T_{ij}}{T_{..}} \right) \log \left(\frac{T_{ij}}{T_{..}} \right)$$

$C = H \times TST$

H shows how the diversity of flows.

E.g., a network with all flows *equally distributed along all links* will have a higher *H*.

$C = A + \Phi$

A: Efficient end-to-end circulation of products

Φ: rebound from the loss or

How to keep the balance?

Both *A* and *Φ* contribute to *robustness*.
But essentially *complementary* and *in opposite direction*.

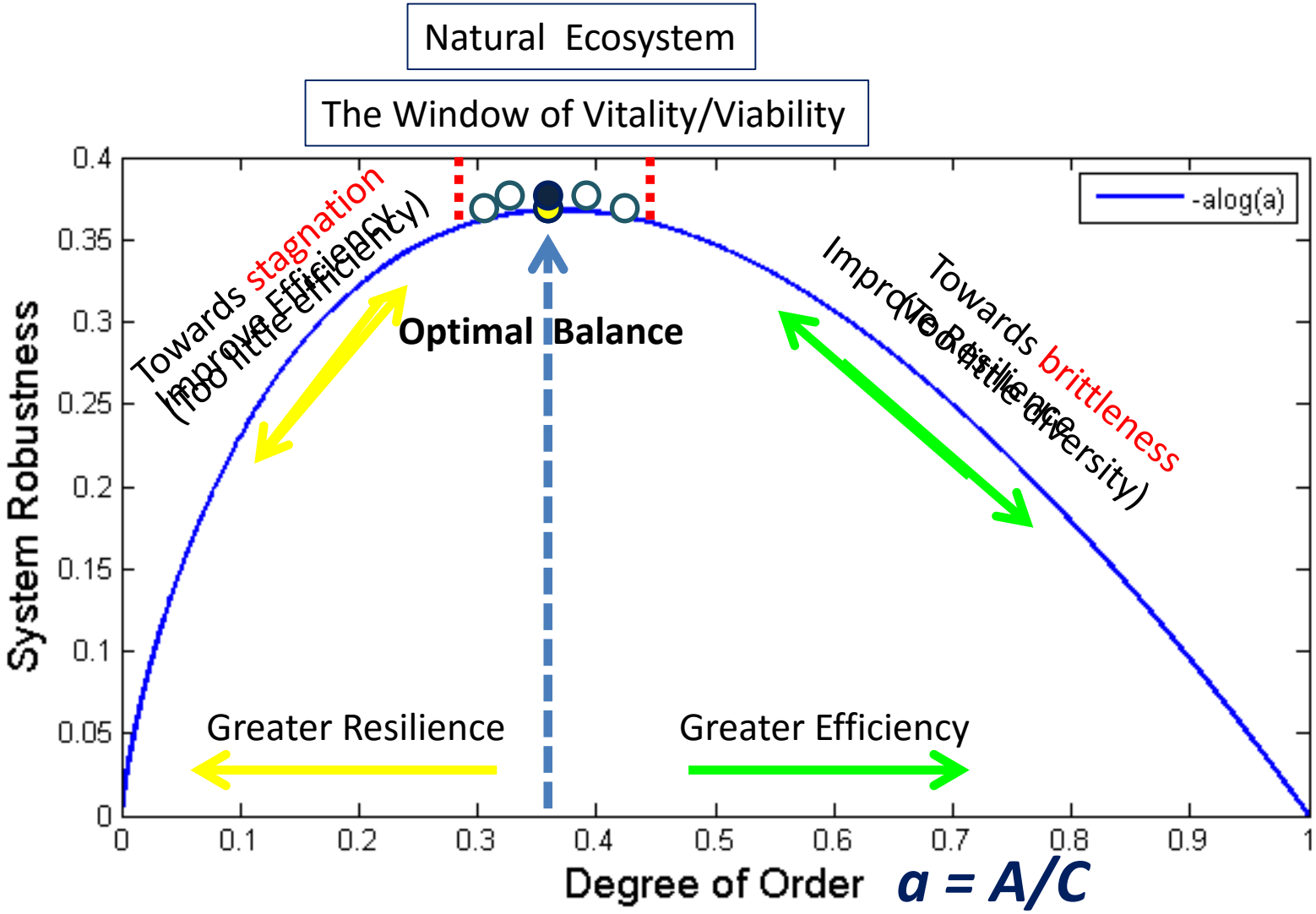
Information-based network indicators

System Robustness (*R*)

$$a = A/C$$

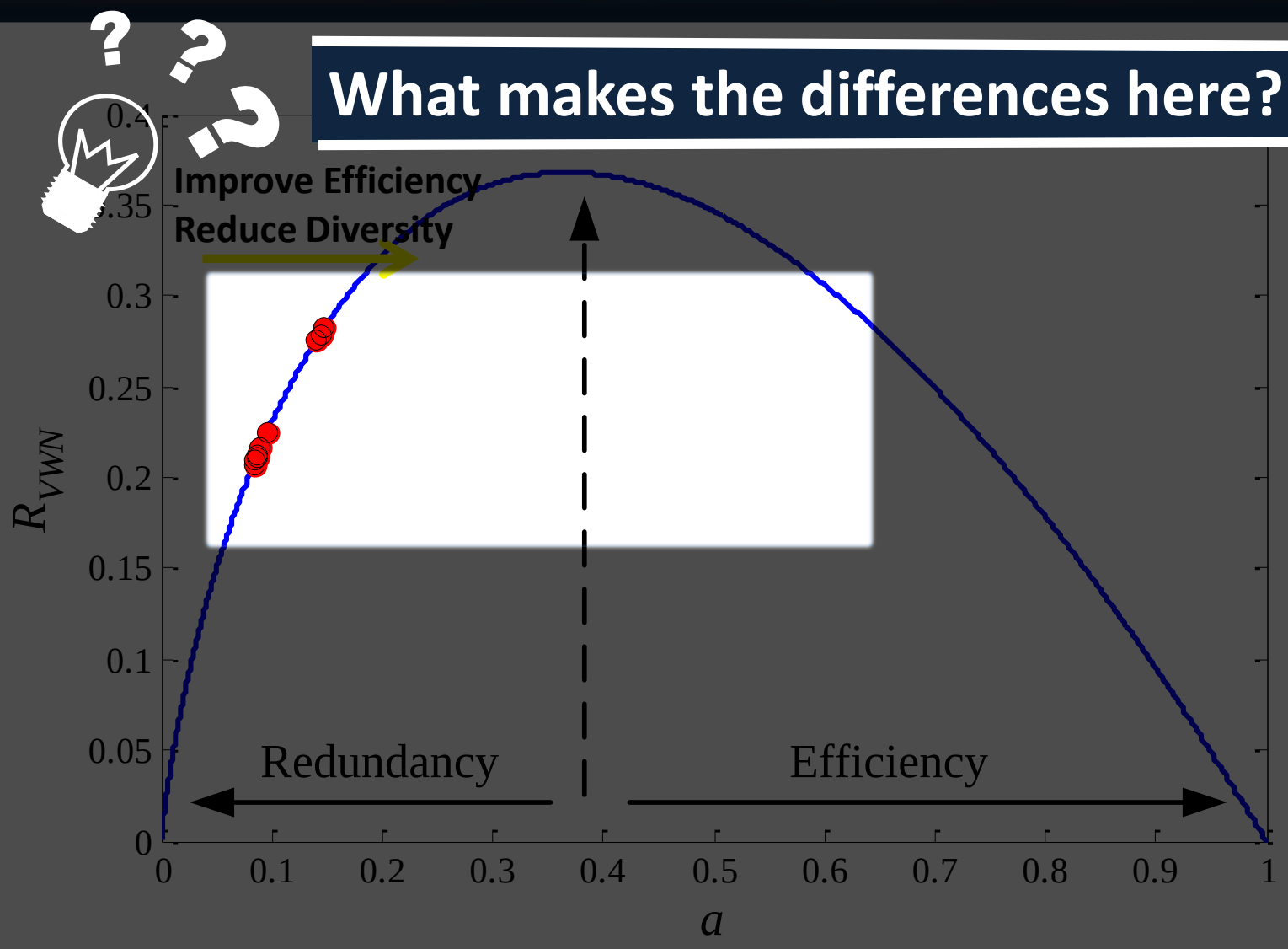
$$R = -k\, a \log(a)$$

System Robustness



Research Results

What makes the differences here?



Flow-based network indicators

Network control analysis

$$\mathbf{CD} = [cd_{ij}] = [n_{ij} - n_{ji}]$$

$$\mathbf{CR} = [cr_{ij}] = \begin{cases} n_{ij} - n_{ji} > 0, \ \mathrm{cr}_{ij} = [\dfrac{n_{ij} - n_{ji}}{\max(n_{ij}, n_{ji})}] \\ n_{ij} - n_{ji} \le 0, \ \mathrm{cr}_{ij} = 0 \end{cases}$$

$$\mathbf{SC} = [sc_j] = [\sum_{k=1}^{n} cd_{kj}]$$

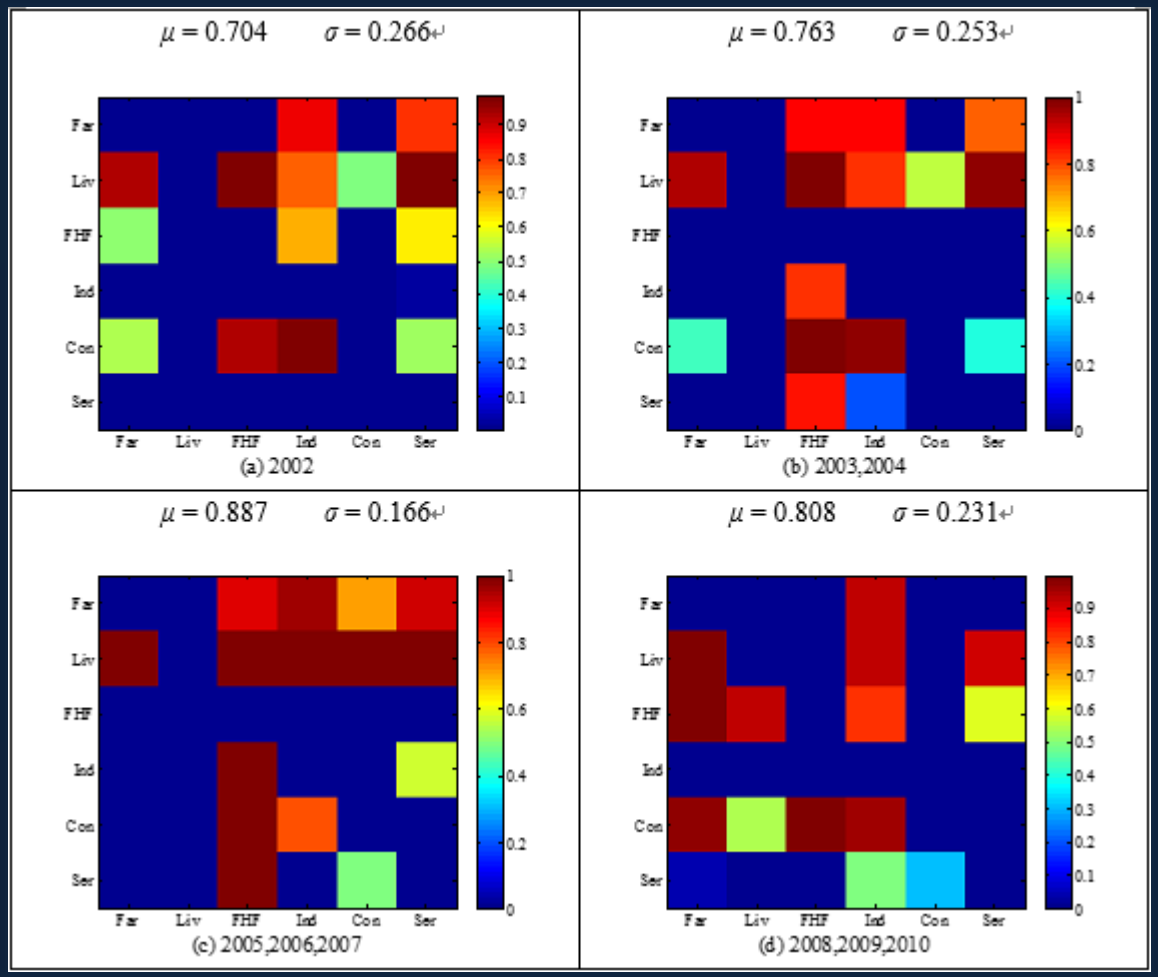
NCA

- To evaluate the control/interdependence degree between sectors within the VWN.
- CD explains the influence of one sector exerted on another within the overall system configuration.
- If the CD value is positive, it stands for the control intensity; otherwise, it shows the dependent intensity.

Results

(6)

Network control Analysis



Stronger pathways :

- Far–Liv
- FHF–Liv
- Ser–Liv
- FHF–Con
- Ind–Con

Weaker pathways:

- Liv–Con
- Ind–Ser
- Ser–Con

Flow-based network indicators

(6)

Network utility Analysis

$$\mathbf{D} = \left[d_{ij} \right] = [\frac{f_{ij} - f_{ji}}{T_i}]$$

$$\mathbf{U} = \mathbf{D}^0 + \mathbf{D}^1 + \mathbf{D}^2 + \cdots + \mathbf{D}^n + \cdots = (\mathbf{I} - \mathbf{D})^{-1}$$

$$NM \equiv SignU(+) / SignU(-)$$

$$SI \equiv \sum_{j=1}^{n} \sum_{i=1}^{n} u_{ij}$$

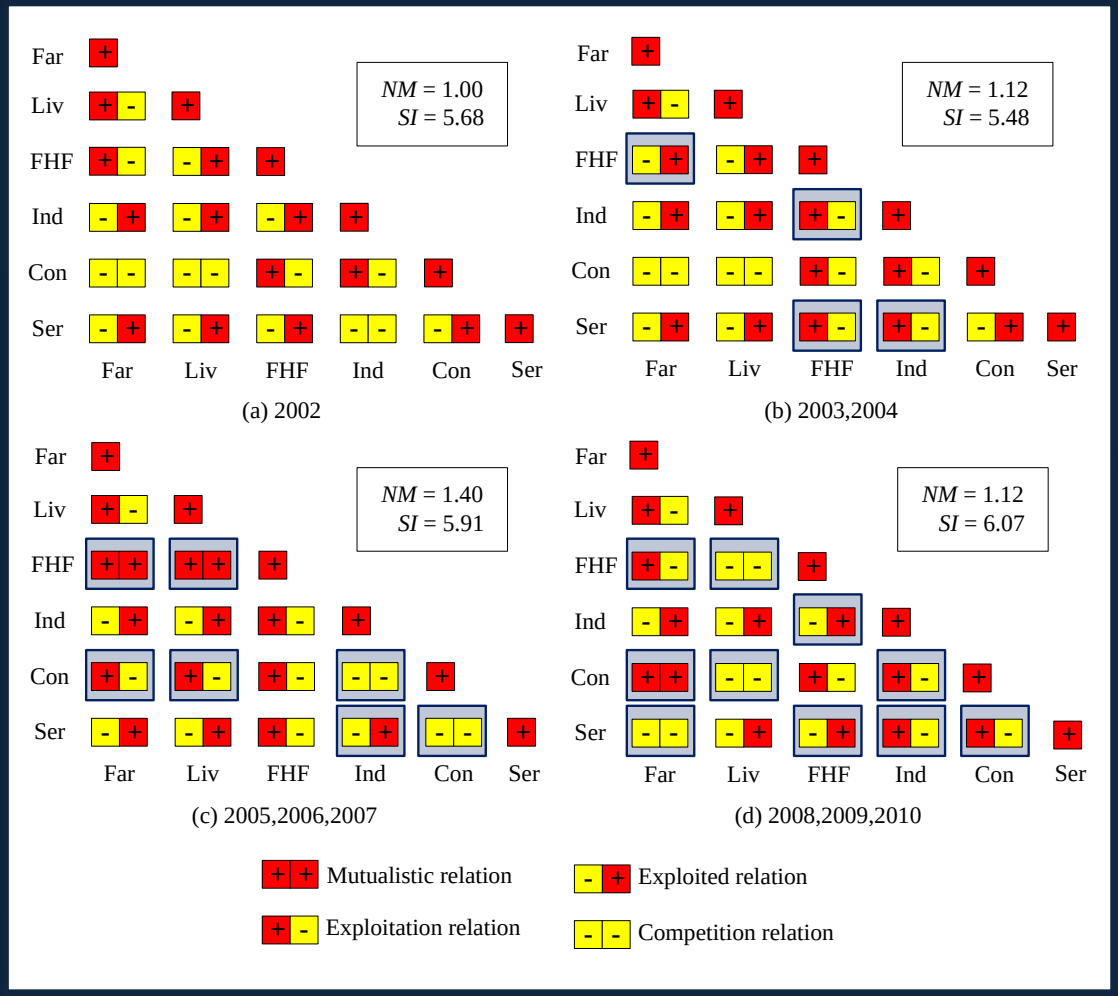
NUA

- Quantifying the net gain or loss of utility between pair-wise sectors in the context of ENA.
- It can be used to investigate the relevant benefit/cost relation between the pair-wise compartments within the network

Results

(6)

Network utility Analysis



- The Exploitative relationship is the dominating one.
- The virtual water transaction structure of network inclines to a relationship of competition between sectors.

Conclusions

- ENA is a powerful tool considering its detailed pathway focused analysis based on the network configuration and nodes' interactions.
- It uncovers the indirect flows and influences hidden in the network systems from a whole systematic perspective.
- ENA can evaluate the stability of the whole system from the balance between efficiency and redundancy, which is vital for the system's stability long-term sustainability.
- The anatomy of the network can be characterized by NCA and NUA based on how flows are distributed within a network at the sectoral and pathway levels.
- It uncovers the dominators and dependents along with the beneficiaries and contributors of the system.


Thank You