学　位　論　文　内　容　の　要　旨

博士の専攻分野の名称　　博士（情報科学）　　氏名　李 杰

学　位　論　文　題　名

Information Dynamics for Complex Ecosystem Prediction and Design
（複雑生態系の予測・設計に関する情報ダイナミクス）

Complex networks theory is introduced to integrate the network of relationships between components in ecosystems. The fundamental work of modeling ecosystems via complex networks is to detect causal interactions between components. In Chapter 1, I review literatures about complex networks and causal inference. It is extremely difficult to infer true causality in real-world ecosystems. The proposed optimal information flow (OIF) model conceptually considers causality information flow and predictability, making the causality practical to quantify. Lastly, I outline the doctoral study and give a brief description for each chapter.

The detection of causal interactions is of great importance when inferring complex ecosystem networks. Convergent cross mapping (CCM) made substantial progress about network inference. In Chapter 2, we investigate the ability of the proposed OIF model to infer bidirectional causality and compare that to CCM. Results from synthetic datasets generated by a mathematical model, data of a real-world sardine-anchovy-temperature system and multispecies fish ecosystem highlight that the proposed OIF performs better than CCM to predict population and community patterns. Specifically, OIF provides higher accuracy and smaller fluctuations of interactions and predictions. We propose an optimal threshold on inferred interactions that maximize accuracy in predicting effective α-diversity, defined as the count of model-inferred interacting species. Thus, OIF can offer a broad ecological information by extracting predictive causal networks ecosystems.

The human microbiome is a complex ecosystem considering the number of bacterial species, their interactions and variability. In Chapter 3, we untangle the complexity of the human microbiome for the Irritable Bowel Syndrome related to gastrointestinal disorder in human populations. Based on a novel information-theoretic network model, we detected species interaction networks that are functionally and structurally different for healthy and unhealthy groups. The top 10 interacting species are the least abundant for the healthy microbiome and the most detrimental. These findings support the idea about the diminishing role of network hubs and how these are defined considering the total outgoing information flow rather than the node degree. The healthy microbiome is characterized by the highest Pareto total species diversity growth rate, the lowest species turnover, and the smallest variability of species abundance. This macroecological characterization of the microbiome is useful for public health and personalized design of pre- and probiotic treatments and microbiome engineering.

Fish ecosystems perform ecological functions that are important for the sustainability of marine ecosystems. Global warming has created novel challenges for fish ecosystems. In Chapter 4, we study a fish community and investigate the relationships between fluctuations of sea temperature and fish community. The fish community is analyzed considering five temperature ranges: $\leq 10°C$, 10–15°C, 15–20°C, 20–25°C, $\geq 25°C$. The OIF model is employed to detect interdependencies between species and reconstruct species interaction networks that are functionally different for temperature ranges. Networks for lower and higher temperature ranges are more scale-free compared to networks for the intermediate 15–20°C range in which the fish ecosystem experiences a phase transition from a local stability to metastability. Species-specific analysis is conducted by calculating the link salience and total outgoing information flow. Native species have a higher total outgoing information flow and are the most salient links. The analyses are useful to formulate science-based fishery policy to maintain marine ecosystems sustainable.

Chapter 5 makes a final conclusion for the doctoral study. The combined results of three studies show methodological and application-specific insights related to information dynamics of ecosystems. It is concluded that complex ecosystems need to be studied not only at individual level, but at system level by investigating the information dynamics of integrated systems. The proposed OIF model presents a strong power in understanding information dynamics and predicting collective behavior in species diversity and populations. More importantly, OIF can be used very well not only in ecosystems, but in many other complex systems.