2019 Annual Report of

Center for Sustainability Science

中央研究院
ACADEMIA SINICA
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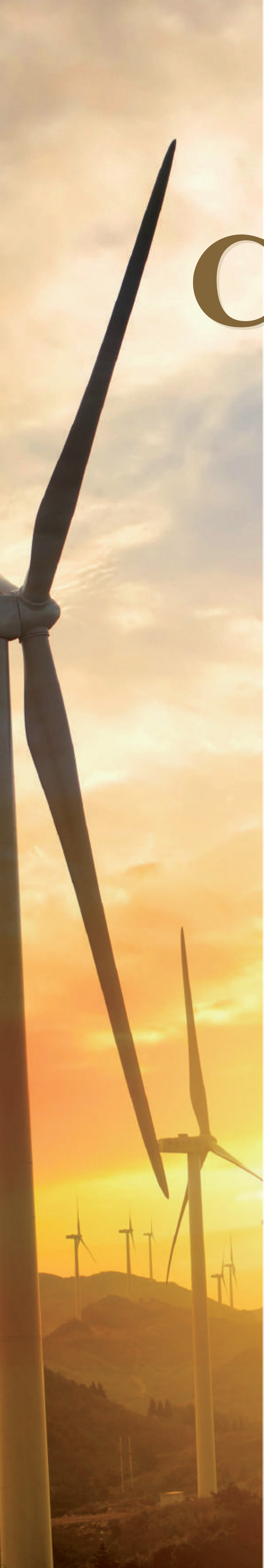
Center for Sustainability Science



Contents

Foreword

2019 has been a dynamic but fruitful year for Academia Sinica's Center for Sustainability Science (CSS). As increasingly resounding voices at the grassroots level worldwide are expressing concern about the climate crisis engulfing on our planet, the need for more effective action to prevent coming disasters is becoming more apparent. Scientists can clearly sense their responsibility, because relevant knowledge will serve as the basis for taking appropriate actions. Academia Sinica established the CSS for just such a purpose: knowledge-building to solve sustainability problems encountered by human society, of which the climate crisis is one of the most critical. In response to these global developments, the CSS organized or co-organized a number of workshops, symposiums, and conferences in 2019. It is worthy to note that one event held in September featured Nobel Laureate Professor Hans Joachim Schellnhuber, who gave a keynote lecture on "The climate challenge and the great transformation," which proved to be a truly stimulating occasion.

This year's CSS research program called for proposals focusing on three main themes: 1) Investigations in Sustainable Energy Development and Problems for Societal Implementation; 2) The Impact of Environmental Changes on Public Health; 3) Environmentally Friendly and Multi-Beneficial Sustainable Agricultural Biotechnology. These themes fully reflect considerations about energy transitions, health risks, and food security under the threat of global warming. Also selected in this report are annual outcome highlights of four completed proposals. Two of them are about technological developments for future forms of sustainable energy; the other two examine issues of food security and biodiversity.

Another CSS mission, its international programs, continued as usual but moved towards more and stronger worldwide engagements. This year the program office of the IRDR ICoE Taipei took the initiative in organizing overseas activities, including special sessions at well-established international congresses. In addition, the program office of Future Earth Taipei established seven working groups to connect with corresponding Knowledge Action Networks (KAN) of the global Future Earth program. Through this new framework and subject channels, we expect to establish stronger forms of interaction between scientists from Taiwan and other countries.

It is my pleasure and privilege to share with you all the progress that the CSS has achieved in 2019. The CSS's growth reflects endeavors towards a new objective for Academia Sinica: fulfilling social responsibilities in crucial areas. One such responsibility is contributing significantly to global efforts in sustainability sciences.

Mei-Yin Chou

Mei-Yin Chou

Chairman, Center for Sustainability Science

Academia Sinica

Center for Sustainability Science

Introduction

Human activities since industrialization have changed the Earth system and these changes have affected the sustainability of natural ecological system and human society conversely. To avoid catastrophic impacts scientists around the world have called for immediate and drastic action hoping to mitigate these problems in time. However, these transboundary problems involve both natural science and social science aspects, which makes them complicated and difficult to study and solve. Nonetheless, it is a great academic challenge to explore the dynamic interaction between human activities and the Earth system and to propose a possible alternative pathway of human development from now on.

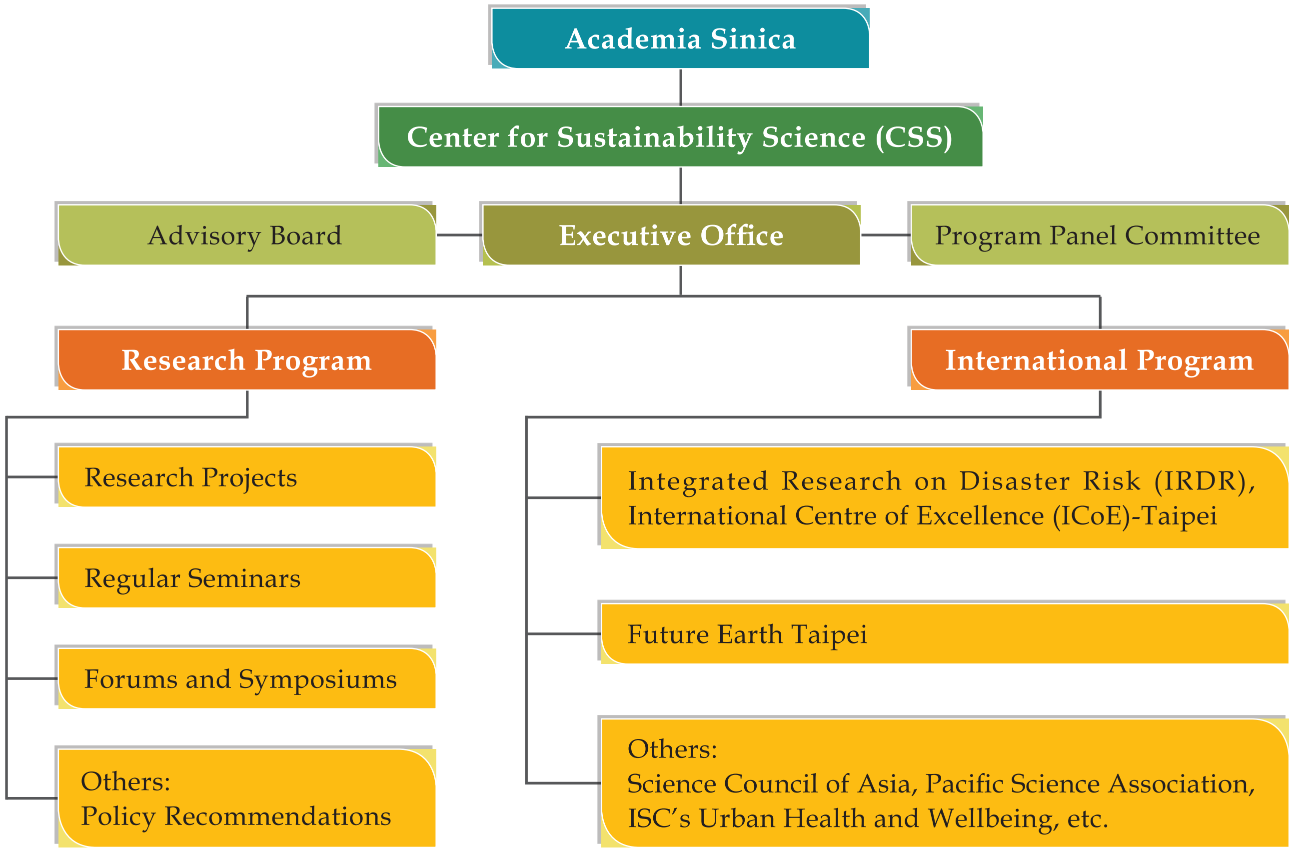
There are 31 diverse research institutes within three divisions in Academia Sinica: Physical Sciences, Life/Medical Sciences, and Humanity/Social Sciences. With numerous outstanding researchers, it is Academia Sinica's social responsibility to take the challenge to provide sound scientific evidence and information to resolve complex sustainability problems. The Center for Sustainability Science (CSS) was established in 2012 to promote researches and activities that strive for the sustainability of the Earth system and human society. The missions of CSS include:

(1) To plan, organize, and promote Sustainability Science Research Program (SSRP), which provides funding on integrated researches that are problem and solution oriented, and interdisciplinary cooperation and stakeholder inclusion approach.

(2) To host Taiwan's branch office of two sustainability science-related international cooperation programs (i.e., IRDR-ICoE and Future Earth) and to bridge Taiwan's researchers with the global sustainability research community.

(3) To provide evidence-based policy recommendations on significant sustainability issues.

Organization and Task



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Domestic Activities

This year, the CSS organized numerous domestic activities to support the operation of Sustainability Science Research Program (SSRP). Additionally, to advocate important sustainability issues, the CSS organized Symposium on Climate Change Mitigation and Energy Transition and received the keynote speaker, Professor Hans Joachim Schellnhuber from Potsdam Institute for Climate Impact Research (PIK). Here are the domestic events in 2019.

Activities to support Sustainability Science Research Program

Open Symposium

In order to promote and encourage application of SSRP, the CSS organized open symposiums to stimulate discussions over important sustainability issues. Two events held in 2019 covered the issues of “Climate, Environment, and Health” and “Energy.” In addition to the introductions of international research programs (i.e., Belmont Forum, Future Earth) and Taiwan’s progress in generating green energy, the events invited the project investigators of six SSRP projects focusing on health and energy to share their research achievements. The events successfully raised attention and facilitated interactions among participants.

Fig.1. Open Symposium on Climate, Environment, and Health held on February 27, 2019

Fig.2. Open Symposium on Energy held on March 7, 2019

Seminars and Outcome Workshops

The CSS organized a series of activities to manage three-year SSRP projects. Seminars were designed for the second-year projects to present the progress of the projects, and outcome workshops were designed for the closed projects to present final research achievements. These events created opportunities for academic exchanges and interactions and showed the accomplishments of SSRP projects. This year, one seminar and two outcome workshops were held for the following three projects.

- Seminar: An Economy-Wide Impact Assessment of Paris Agreement on Taiwan’s Environmental Governance and Renewable Energy Development Strategies Towards a Low-Carbon Society.
- Outcome Workshop: Taiwan Drought Study: Change, Water Resource Impacts, and Risk Perception and Communication
- Outcome Workshop: Disaster Resiliency through Big Open Data and Smart Things (DRBoaST)

Fig.3. Seminar on Economic Impact of Paris Agreement held on September 26, 2019

Fig.4. Outcome Workshop on Open Data in Disaster Response held on October 2, 2019

Fig.5. Outcome Workshop on Climate Change Drought Study held on November 4, 2019

Activities to advocate sustainability issues

Symposium on Climate Change Mitigation and Energy Transition

This year, the CSS had a valuable opportunity to receive a Germany delegation—Professor Hans Joachim Schellnhuber and Dr. Daniel Klingenfeld from Potsdam Institute for Climate Impact Research (PIK). To advocate the importance of climate emergency, the CSS organized Symposium on Climate Change Mitigation and Energy Transition in Academia Sinica. The PIK guests gave two talks on “The climate challenge and the great transformation” and “Feasible decarbonization pathways and policies for climate stabilization.” Taiwanese researchers also elaborated Taiwan’s progress in renewable energy, energy transition and climate policy. This event invited over 100 Taiwanese researchers and stakeholders attending and inspired a lot of fruitful discussion and interactions.

Fig.6. President James C. Liao of AS gave an opening remark in the Symposium on September 11, 2019

Fig.7. Prof. Hans Schellnhuber gave the Keynote Speech in the Symposium and there are over 100 participants.

Fig.8. Panel Discussion in Symposium on Climate Change Mitigation and Energy Transition on September 11, 2019

PIK’s Visit in Taiwan

In addition to the symposium, the CSS arranged these PIK guests’ visit to several agencies to exchange opinions. These agencies included: Vice President’s Office, Academia Sinica, Ministry of Science and Technology (MOST), National Science and Technology Center for Disaster Reduction (NCDR), Ministry of Foreign Affairs, and German Institute Taipei. This visit not only enhanced mutual understanding but facilitated Taiwan-Germany future collaborations.

Fig.9. PIK delegation met Vice President Chien-Jen Chen on September 9, 2019

Fig. 10. PIK delegation met Minister Liang-Gee Chen of Ministry of Science and Technology and Director Hongey Chen of National Science and Technology Center for Disaster Reduction on September 10, 2019

Research Program

The Sustainability Science Research Program emphasizes on transdisciplinary scientific research. It aims at synthesizing the research results of different dimensions and applying the results on solving problems of sustainable development for human society. The current focal themes include the following six research orientations.

Energy and Decarbonization Technologies

Food, Air, and Water Security and Safety

Transformation towards Sustainable Society

Health and Environmental Changes

Earth System under Global Changes

Disaster Prevention, Reduction and Recovery

The achievements of four following SSRP projects are introduced in this annual report.

- **Biological Impacts of Climate Change on Mountain Regions: An Integrative Study**
- **Development of Novel Thermoelectric Materials for Sustainable Energy**
- **Effects of Environmental Changes on Rice Growth and Production in Taiwan**
- **Development of Next-generation Sustainable Photovoltaic Energy**

Biological Impacts of Climate Change on Mountain Regions: An Integrative Study

Project starting year: 2017

Hosting Institute: Biodiversity Research Center, Academia Sinica

Research Objectives

Approximately 25% of global land area is covered by mountains. Mountain-based resources, directly and indirectly, maintain over half of the global population. The sustainability of human society also strongly depends on mountain biodiversity because plants and animals in mountain regions may provide current and future generations with new resources to produce food, energy, and pharmaceuticals, in addition to providing aesthetic enjoyment and other desired commodities and services. However, despite its importance, determining the rate of warming in mountainous regions is extremely difficult because of limited direct long-term climate data. Similarly, the velocity of mountain climate change has unexpectedly been a poor predictor of the shift in the distribution of mountain species. No satisfactory explanation for this discrepancy has been identified. The lack of predictability of current theories suggests that we still have a limited understanding of species range limits and range size, which are fundamental to understand the effect of climate on living organisms. However, knowledge of the physical environments in mountain regions and how they will be influenced by climate change are crucial for predicting how climate change will affect mountain species. Therefore, the objectives of our study are to fill these knowledge gaps and provide crucial data for understanding climate change in mountain areas and its ecological effects.

Main Results to Date

Four main breakthroughs have emerged from our project thus far.

(1) We provided the first global assessment of the velocity of mountain climate change by applying thermal dynamic theory and deriving the moist adiabatic lapse rate (MALR) from local surface temperature and water vapor. We observed that MALR varies substantially between 3 and 9 °C km^{-1} worldwide. By using this approach, we identified 24 high-velocity mountain regions and observed that increasing surface temperature leads to higher climate velocity, particularly in dry mountain regions. Notably, high climate velocity could also occur in wet regions with lower lapse rates, such as the mountains in northern Sumatra, western Guiana Shield, northern Andes, Costa Rica, Nepal, and Madagascar. We also found that topographical factors, such as aspect and mountain orientation, influence climate velocity. Subsequently, we re-estimated the rates at which species must shift to keep pace with climate change. We observed that the degree of lagging may have been overestimated in previous meta-analyses. In

cases of low climate velocity, mountain species track reasonably well with climate velocity. By contrast, upslope migration of mountain species substantially lagged underlying the climate change in regions with higher climate velocity. Our study aided in identifying mountains with high climate velocity, which can inform conservation priorities as well as provide a more suitable physical basis for understanding the ecological effects of climate change in mountain regions (Fig. 1).

(2) The most influential hypothesis regarding species geographic limits suggests that abiotic factors constrain distribution boundaries of species in harsh environments, such as high elevation or high latitude, whereas interspecific competition sets range boundaries at more benign environments. However, it has long been recognized—at least since Darwin's *On the Origin of Species*—that a harsh climate strengthens competition and sets species range limits. Nevertheless, in both harsh and benign environments, competition can be mediated by climate, which then becomes the chief factor constraining species distribution. No thorough test of this mechanism has been conducted thus far. We used comprehensive experimental manipulations to reveal for the first time that temperature determined the competition type and set the upper and lower elevational range limits of Asian burying beetles (*Nicrophorus nepalensis*). We investigated the distribution and breeding performance of *N. nepalensis* and how they interacted with blowflies to use their key breeding resource, namely carcasses. At the lower elevational limit, higher temperature allowed blowflies to grow at high rates and consume carcasses rapidly. *N. nepalensis* could detect the carcasses and arrive quickly, but intense interference competition nevertheless determined their breeding success and constrained distribution. By contrast, at the upper elevational limit, cool temperature inhibited both blowfly and maggot activity and carcass volatile emissions, upon which *N. nepalensis* rely to detect carcasses. The time required to locate carcasses determined their breeding success, representing typical exploitative competition. In summary, we noted a transition from interference to exploitative competition along the elevation gradient. The transition reflects Darwin's classic hypothesis that benign climates facilitate direct competition for highly accessible resources, whereas harsh climates

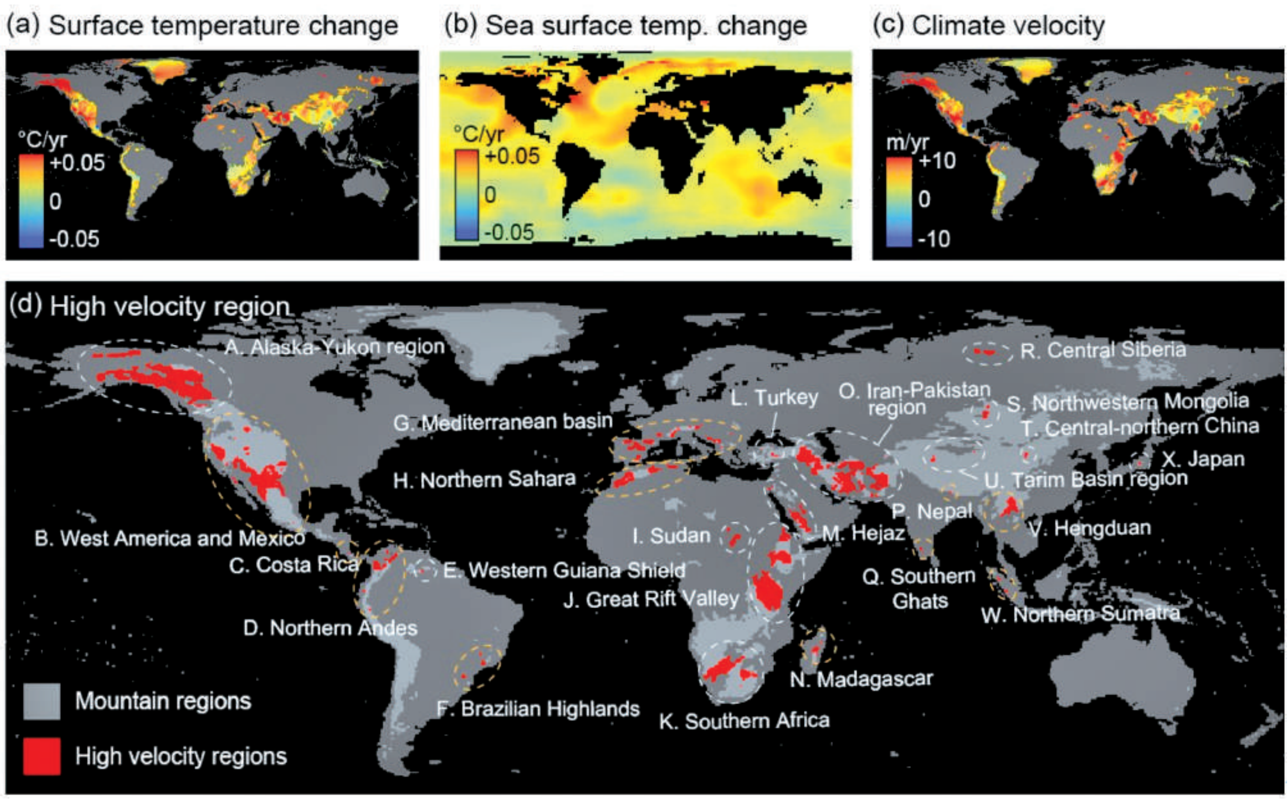

Fig. 1. The velocity of climate change in global mountains from 1971 to 2015. Terrestrial (a) and sea (b) surface temperature change (1971-1975 V.S. 2011-2015) and derived climate velocities in mountains (c). (d) The high climate-velocity mountains are defined as where the isotherms have shifted more than one standard deviation of the global mean value (higher than 8.45 m yr^{-1}).

strengthen competition, through high rivalry, that ultimately sets the range limits. Understanding how ecology influences the range limits of species provides crucial information on the ecological effects of climate change. Our study indicated that species interaction (indirect effect) rather than the direct effect of temperature was key in determining the range limits of burying beetles (Fig. 2).

(3) Understanding how phenotypic traits vary among populations inhabiting different environments is critical for predicting a species' vulnerability to climate change. However, little is known about the key functional traits that determine the distribution of populations and the alternative mechanisms—phenotypic plasticity versus local adaptation—underlying intraspecific functional trait variation. By using *N. nepalensis* burying beetles, we demonstrated that mountain ranges differing in elevation and latitude offer unique thermal environments in which two functional traits, namely thermal tolerance and reproductive photoperiodism, interact to shape breeding phenology. We revealed that populations on different mountain ranges maintain similar thermal tolerance, but differ in reproductive photoperiodism. Through common garden and reciprocal transplant experiments, we confirmed that reproductive photoperiodism is locally adapted and is not plastic phenotypically. Accordingly, year-round breeding populations on mountains of intermediate elevation are likely to be most susceptible to future warming because maladaptation occurs when beetles attempt to breed at warmer temperatures (Fig. 3).

(4) Animal coloration has fascinated biologists at least since Wallace. However, explaining color variation among animals at broad geographic scales remains challenging, largely because of the inherent difficulties in objectively extracting informative color and shape pattern features—a problem also faced in computer vision studies. Here, we demonstrated how deep learning—a form of artificial intelligence (AI)—can not only reveal subtle and robust patterns of color feature variation along elevational gradients

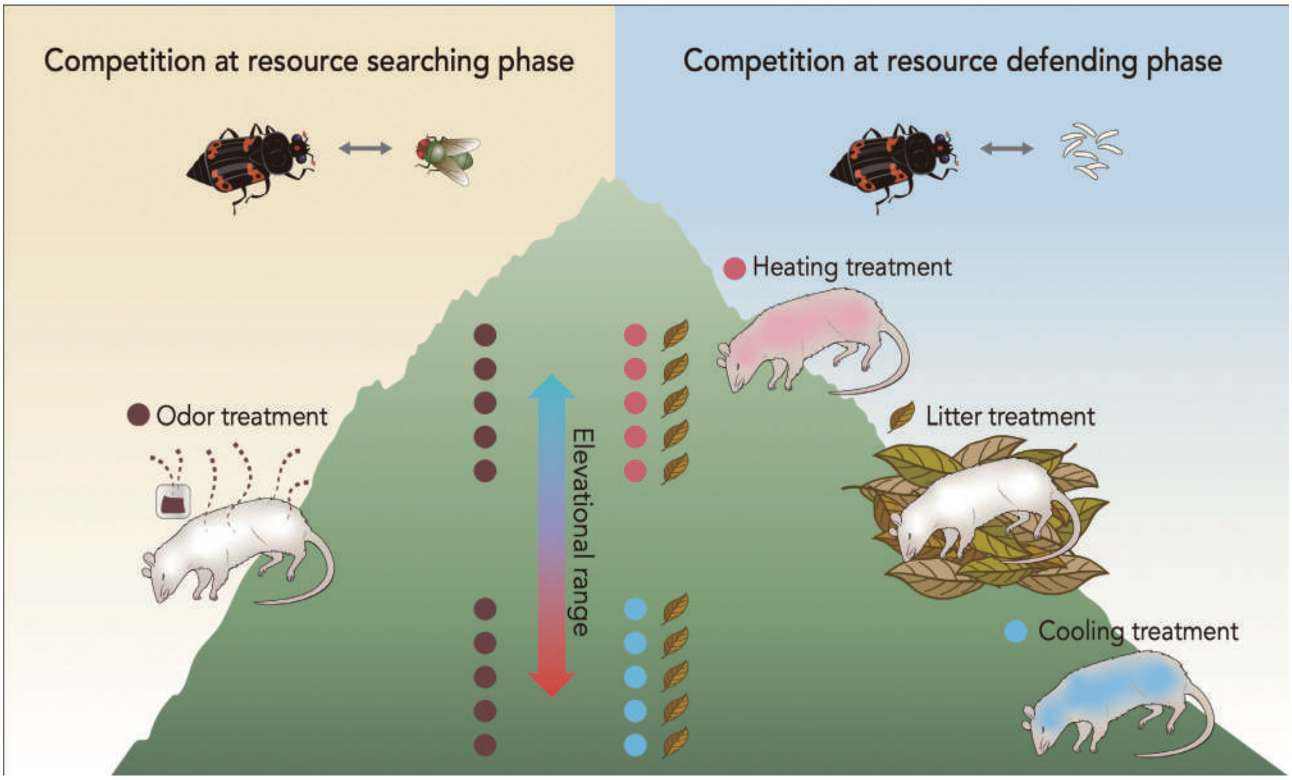

Fig. 2. The summary of manipulation experiments to investigate the causes of range limits in *N. nepalensis.* We tested the mechanisms of competition with blowflies and how these affect the probability of breeding successfully which, ultimately, set range limits for *N. nepalensis*. We applied odor treatments to test the effect of competition at the resource searching phase and the treatments of heating, cooling, and litter addition to examine the effect of competition during the resource defending phase.

but also aid in identifying the mechanisms underlying the generation of these biogeographic patterns. By using more than 20,000 images with precise GPS information of nearly 2,000 moth species in Taiwan, our deep learning model generated a 2048-dimension feature vector that accurately predicted the elevational distribution of moth species based on images alone. By using this multidimensional feature vector to investigate how biotic and abiotic factors drive color pattern trait variation at the assemblage level, we determined that within-assemblage image trait variation was smaller in high-elevation assemblages. Structural equation modeling suggested that this reduced image trait diversity is likely the result of colder environments selecting for darker coloration, which in turn limits the color pattern trait diversity of assemblages at high elevations. Finally, with the help of deep learning, we reported that color pattern trait diversity at the assemblage level is higher when environmental constraints on color are smaller in warm environments. Therefore, this study aided in understanding the possible moth response to warming. The use of AI can aid in identifying the species more vulnerable to climate change, such as those with narrower distribution (Fig. 4).

Future Research Plan

We will continue our study on mountain climate change, burying beetle ecology, and distribution and color analysis of moths in the future.

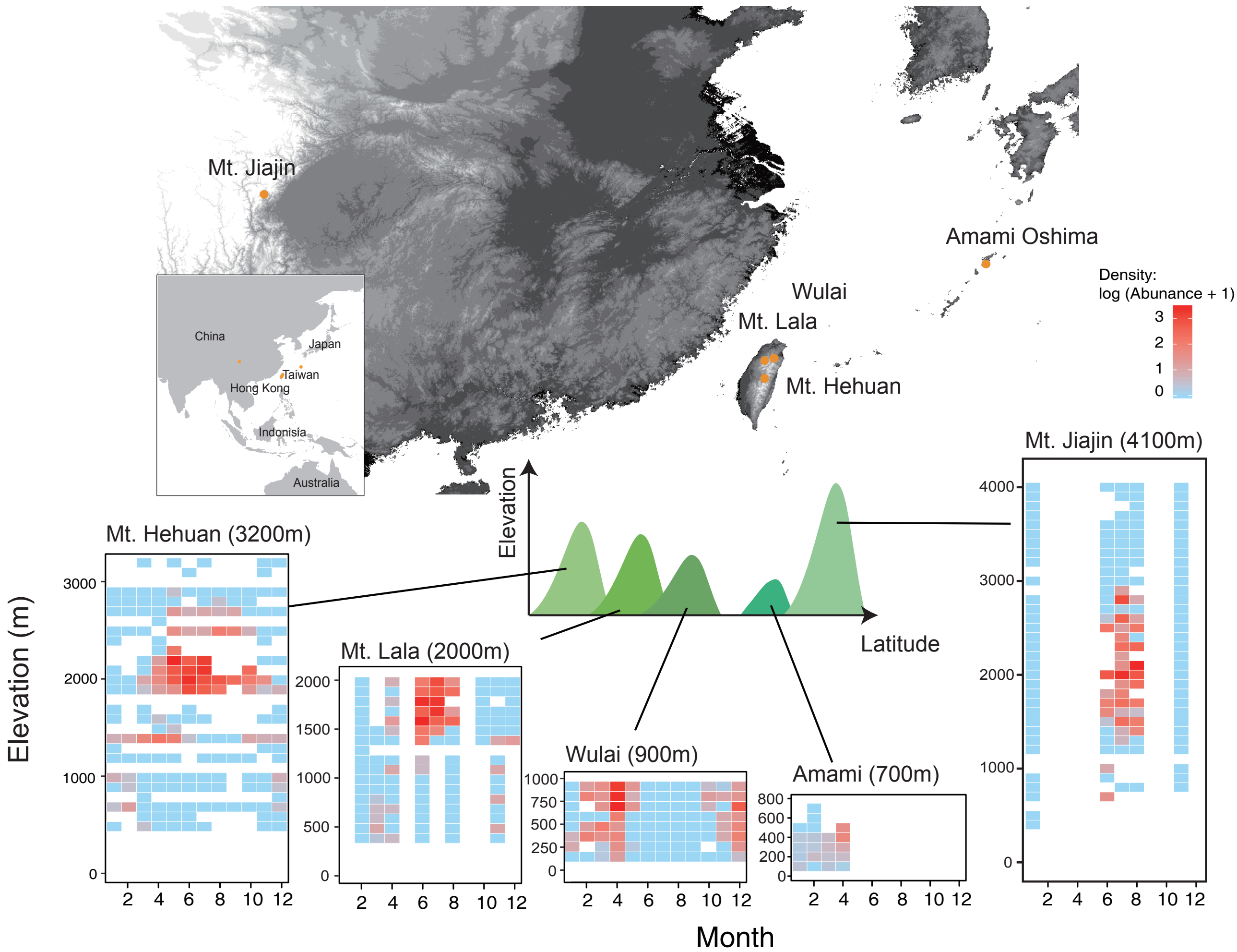

Fig. 3. Map depicting the mountain ranges sampled and heatmaps of the spatial-temporal distributions of population density along the elevational gradient at each location. Abundance values were log-transformed according to the formula log (amount+1). The color scale indicates the difference in the abundance of beetles at the five mountain ranges. The maximum elevation of each mountain range (indicated on the map by orange circles) is given in parentheses.

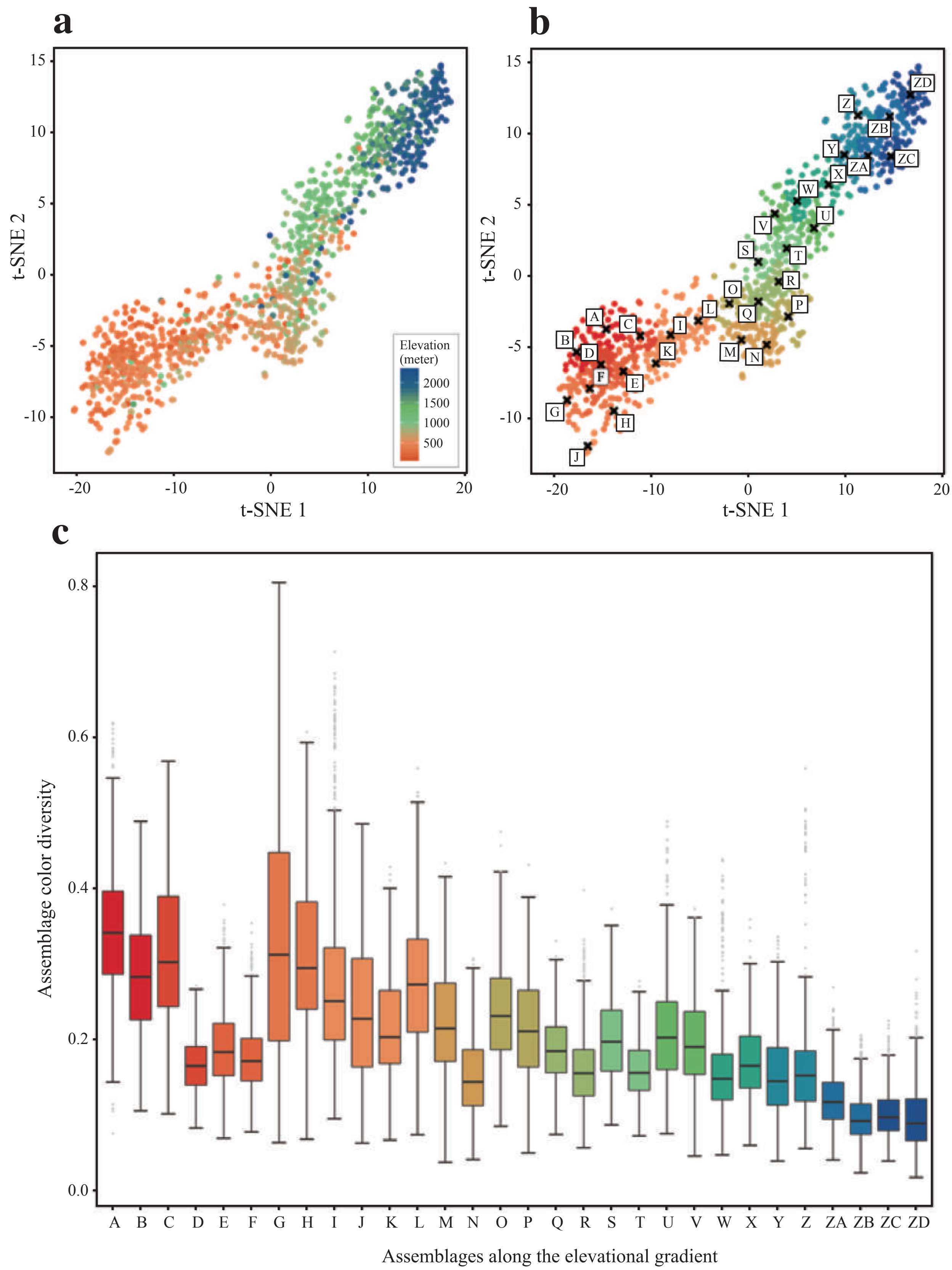

Fig. 4. Dimensionality reduction visualization of image features and within-assemblage colour diversity of moths. (a) A t-Distributed Stochastic Neighbor Embedding (t-SNE) visualization of the 2048-dimension feature vector of species in relation to the moths' elevational distribution. (b) Species assemblages were identified by applying k-means clustering to the t-SNE map. There are 30 species assemblages in total. (c) Within-assemblage colour diversity along the elevational gradients was defined as the trait distance between any two species within the same assemblage as the cosine distance of their 2048-dimension feature vectors.

Publications

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2. Chan, S.-F. , W.-K. Shih, A.-Y. Chang, S.-F. Shen* and I.-C. Chen*, (2019), Contrasting forms of competition set elevational range limits of species, *Ecology Letters,* DOI: 10.1111/ele.13342.
3. Tsai, H.-Y., D. R. Rubenstein, Y.-M. Fan, T.-N. Yuan, B.-F. Chen, Y. Tan, I.-C. Chen* and S.-F. Shen*. (Accepted). Locally-adapted phenology determines population vulnerability to climate change. *Nature Communications.*
4. Chan, W.-P., C.-D. Thomas, H.-C. Kuo, I.-C. Chen*, and S.-F. Shen*. (submitted). The velocity of climate change and species tracking in global mountains.

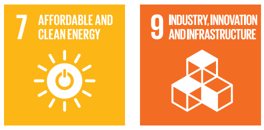
Project Director: **Mao-Ning Tuanmu, Assistant research fellow**

Dr. Mao-Ning Tuanmu is interested in the spatiotemporal patterns of biodiversity, the underlying processes and their implications for biodiversity conservation. His research characterizes biodiversity patterns across spatial and temporal scales using remote sensing, acoustic sensing and open biodiversity data. He also integrates ecological modeling, big data analyses and machine learning to understand how biodiversity responds to human-induced environmental changes. He is currently the Executive Director of the Center for Systematics and Biodiversity Informatics, which aims to integrate biodiversity information in Taiwan, facilitate data opening and mobilization, and provide data infrastructure for biodiversity research and decision-making.

Sub-Project PI, Co-PI:

Dr. Lin, Po-Hsiung, AS, NTU	Dr. Shen, Sheng-Feng, BRC, AS
Dr. Ho, Yao-Hua, CSIE, NTNU	Dr. Chen, I-Ching, LS, NCKU

Development of Novel Thermoelectric Materials for Sustainable Energy



Project starting year: 2017

Hosting Institute: Institute of Atomic and Molecular Sciences, Academia Sinica

Research Objectives

The objective of this project is to develop novel thermoelectric materials for application in sustainable energies. Fundamental concepts and new thermoelectric ideas are also covered in this project.

Main Results to Date

Over the last few years, the interdisciplinary team lead by Kuei-Hsien Chen has extensively evaluated candidate materials for use in thermoelectric conversion, including the materials' synthesis, characterization, and device manufacture. The research has been fruitful and the results have been published in leading international journals. For example, bulk and thin-film forms of *p*-type IV–VI semiconductor GeTe and its derivatives are now thoroughly understood. In this material, the inherently high number of Ge vacancies can now be suppressed, which retains the phase-change material in rhombohedral R3m symmetry at temperatures up to 773 K and increases the dimensionless thermoelectric figure of merit zT from 0.8 to a record high of 1.4 [1]. Replacing Ge with an electron donor, such as Sb or Bi, not only moderates the power factor but also substantially inhibits the thermal conductivity, with zT ≈ 2.3 ultimately achieved [2,3]. A further improved power factor of $55\mu W/cm\text{-}K^2$ can be achieved for thin Ge–Sb–Te films (Fig. 1) that crystallize into a metastable cubic structure on silicon substrate as a result of rapid annealing and quenching. High-temperature electrical transport measurement and photoelectron spectroscopy have revealed thermal-induced electronic band modulation and more favorable effective mass and band position at temperatures higher than 423 K [4].

Another IV–VI semiconductor, SnSe, has recently attracted considerable attention because of its high zT = 2.6 and ultralow thermal conductivity along a specific crystallographic direction. In addition to being inexpensive, SnSe's highly anharmonic lattice and having of covalent/metavalent bonding agree with the "Phonon Glass, Electron Crystal" concept, and electrical and thermal transport can be manipulated independently. Dr. Yang-Yuan Chen and co-workers have fabricated superior SnSe single crystals, revisited the material's anisotropic transport properties, and corrected the controversial findings of L. D. Zhao *et al.* in *Nature* [5]. The anisotropic thermal conductivity of the SnSe single crystals was correlated with anharmonicity and phonon–phonon interaction; these correlations were obtained through measurements of heat capacity and direct measurements using temperature-dependent polarized Raman scattering [6].

Our experts Dr. Chih-Wei Chang and Dr. Wen-Pin Hsieh have established advanced probes and performed 2ω/3ω AC analysis and time-domain thermal reflectance (TDTR) to determine thermal transport in thin films and low-dimensional nanostructures. Direct experimental observation of nonlocal thermal conduction was accomplished in SiGe nanowires and carbon nanotubes anchored in a three-terminal fixture. As illustrated in Figure 2, the schematic of a three-terminal thermoelectric device to show the non-local thermal transport for enhanced thermoelectric property. In our experiment, a 16% nonlocal effect was discovered in a 10-μm-long carbon nanotube but was absent when the length was 70 or 150 μm. Because carbon nanotubes have been demonstrated to display anomalous thermal conduction when their lengths exceed 10 μm, they are conventional ballistic thermal conductors when they are shorter than 10 μm. The critical length of 10 μm suggests that occurrences of the nonlocal effect and anomalous thermal conduction are not correlated. Two manuscripts detailing on these results will soon be submitted for publication.

Finally, with the help of first-principles calculations, an effort led by Dr. Ching-Ming Wei, SnSe, Ge–Sb–Te, and other new thermoelectric materials have been better understood. Such prior theoretical selection of new materials minimizes the likelihood of failure in expensive experimental synthesis and characterization and is thus highly desirable in future thermoelectric research.

As for the facilities available to the team, in addition to the commercialized ZEM and LFA analysis systems, the team has access to the most advanced facilities in this field, such as world-class micro-/nano-fabrication and characterization laboratories at Academia Sinica, National Taiwan University, and National Tsing Hua University; X-ray analysis equipment at the National Synchrotron Radiation Research Center; and neutron scattering equipment at the Australian Nuclear Science and Technology Organisation. Over the years, extensive knowledge has been acquired. The consortium has also engaged in international collaboration in the past few years, such as collaboration with J. Snyder and V. Dravid at Northwestern University, M. Aono and T. Mori at the National Institute for Materials Science in Japan, and P. Rogl and E. Baur at Vienna University. Visits to these institutions and the exchange of samples and ideas are routinely conducted.

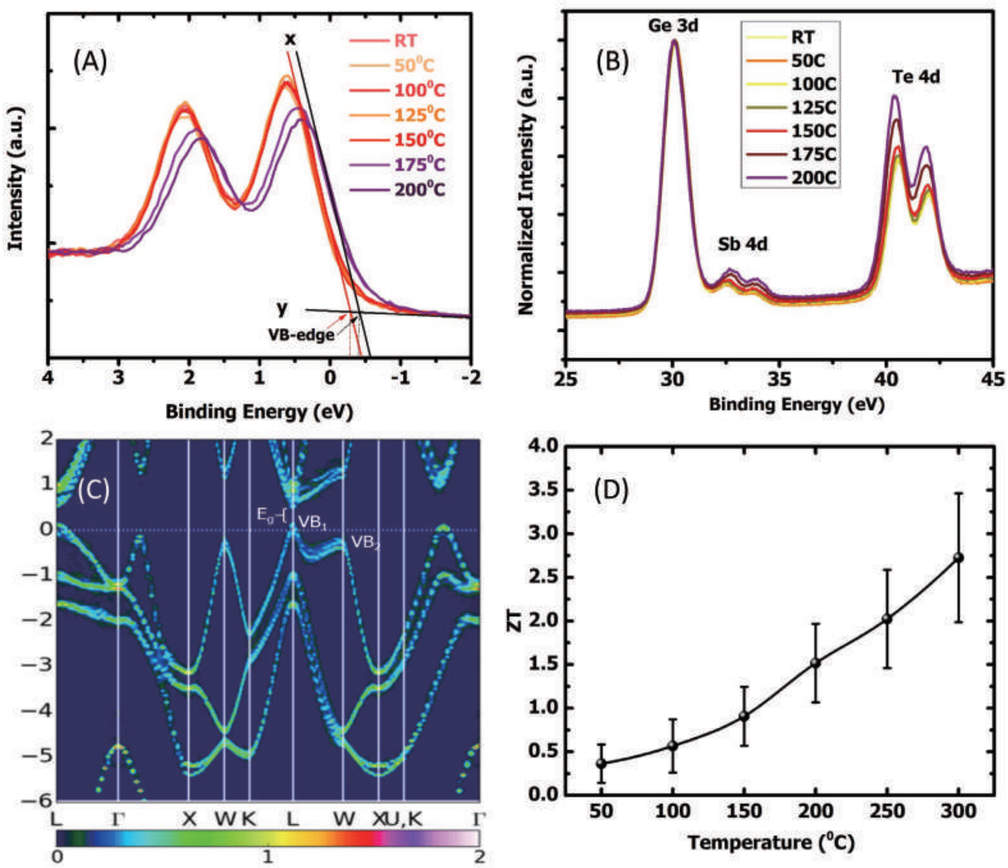


Fig. 1. (A) and (B) UPS and XPS spectra of the GST films showing the shift of valance band edge at different temperatures; (C) Band structure of the GeTe using DFT calculation; (D) Thermoelectric figure-of-merit (zT) for the GST films.

Future Research Plan

Our material exploration will continue with a greater emphasis on abundant and ecofriendly materials such as SnSe, Cu_2S, and Si-based alloys. Additionally, we aim to obtain a fundamental understanding of electron and phonon transport and energy band structures, based on theoretical derivation and experimental findings. The ultimate goal is to develop viable thermoelectric materials for use in daily life.

Most team members will stay on and extend their findings on thermoelectrics. Dr. Chih-Wei Chang and Dr. Wen-Pin Hsieh will continue their investigation of nonlocal thermal transport. Dr. Yang-Yuan Chen will focus on devices made using SnSe-based and $(Bi,Sb)_2(Te,Se)_3$ crystals either through floating-zone crystal growth, spark-plasma sintering, or sputter deposition, with these devices aimed at applications in power generation and refrigeration, in addition to other applications relevant to daily life. Dr. Raman Sankar has already demonstrated excellent control of defects in GeTe compounds. Further improvement can be expected from the use of In or Ga, which can boost thermopower and generate resonance levels near the Fermi level.

The project director and Dr. Li-Chyong Chen will focus on the development of inexpensive thermoelectric materials. They have much experience with copper (I) sulfide (Cu_2S), an abundant and well-performing semiconductor. However, liquid-like copper, despite having extremely low thermal conductivity, migrates under an electric field at high temperature, causing instability. By including pyrolysis under reduced atmosphere, our new Cu-based metal–organic framework [7], in which the -(Cu-S)- layer is sandwiched between organic slabs, makes possible the production of a laminated Cu_2S/graphene heterostructure. Additionally, we plan to investigate economical Si-based materials. Silicon, a highly developed industrial semiconductors, has not only high thermal conductivity but also an excellent power factor. Silicon will be alloyed through nonequilibrium "top-down" ball-milling or "bottom-up" sputter deposition for mesoscopic grain boundary engineering and the energy filtering process, boosting the Seebeck coefficient and annihilating a broad spectrum of phonons.

We have invited from National Tsing Hua University's Prof. Chien-Nerng Liao, a veteran in thermoelectrics and electronic materials, to enrich our knowledge regarding the interface between semiconductors and metal contacts, which is the critical factor in the manufacture of high-performance devices.

Dr. Chin-Ming Wei will continue to theoretically analyze the physical properties of thermoelectric materials. Using Boltzmann's theory, the electronic transport parameters of a crystal can be calculated semiclassically. Energy band dispersions provide information on group velocities and mass tensors, and the momentum-dependent conductivity tensor can then be determined by employing a reasonable relaxation time model. After a careful sum over the Brillouin zone for relevant quantities and derivatives, the temperature-dependent Seebeck coefficient S, electric conductivity σ, and electronic thermal conductivity κ_e can be determined on the basis of detailed knowledge of the electronic structure.

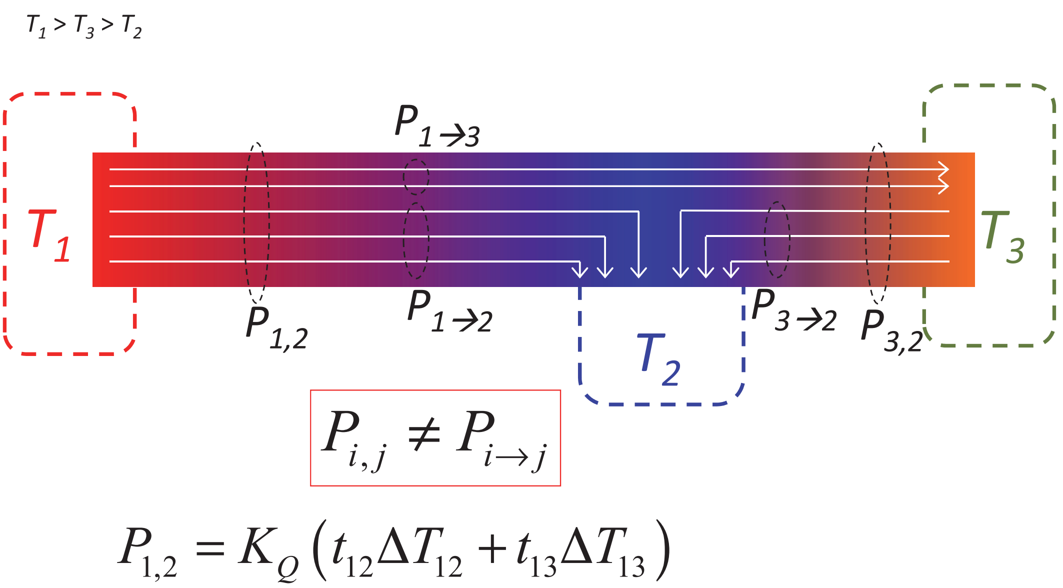


Fig. 2. Schematic of a three-terminal thermoelectric device to illustrate non-local thermal transport for enhanced thermoelectric property.

To summarize, we foresee better understanding of the electronic and phononic band structure of materials with high thermoelectric potentials—such as GeTe, SnSe, and Cu_2S—as well as designated dopants and vacancies. A high zT of 3.0 or greater at high temperature and 1.0 near room temperature will be achieved, and the growth and characterization of thin film thermoelectric materials will be established for low-temperature Peltier coolers.

The conversion of waste heat to electricity is of great importance to society. The recovery of waste heat from automobiles, resulting in energy savings of 10%, can be significant when low-cost thermoelectric devices are used. Waste heat recovery can also be applied in industries with large heat exhaust, such as in steel companies and oil refineries. Low-temperature thermoelectric materials are highly desirable for cooling applications. The materials will have niche applications, such as in the cooling of GPS devices in guided missiles and CPUs in computers. In particular, thermoelectricity applications for CPU cooling in high-performance computing facilities are likely to be have a high future market demand.

Various emerging applications exist for thermoelectric devices, such as thermoelectric sensing and imaging for the detection of infrared and terahertz signals through heat detection. Security and medical applications in this direction are also emerging. In such applications, a high power factor, rather than zT, will be crucial to obtaining high sensitivity.

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2. Sankar *et al.,* Cryst. Eng. Comm. **17**, 3440-3445 (2015).

3. Bayikadi *et al.,* manuscript submitted.

4. Wong *et al.,* ACS Appl. Electron. Mater. **1**, 2619-2625 (2019).

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Project Director: **Kuei-Hsien Chen**

Dr. Kuei-Hsien Chen is Distinguished Research Fellow and Director in Institute of Atomic and Molecular Sciences, Academia Sinica. He has long experience in the synthesis and characterization of advanced materials with the aim for energy applications such as thermoelectric, photovoltaic, solar fuels, and lithium-ion battery. He is devoted to the development of earth-abundant and low-cost thermoelectric materials.

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Effects of Environmental Changes on Rice Growth and Production in Taiwan

Project starting year: 2017

Hosting Institute: Agricultural Biotechnology Research Center, Academia Sinica

Research Objectives

We have assembled a multiple-institution team to study the effects of climate change on rice crops in Taiwan. We will address the problem posed by a critical rice disease, the rice sheath blight disease (紋枯病) caused by the fungal pathogen *Rhizoctonia solani*. Furthermore, on the basis of our findings obtained in the past three years, we will investigate the molecular mechanisms of heat stress tolerance and nutrient utilization and generate rice breeds that are more efficient at utilizing nutrients. The project consists of six subprojects that cover the following topics.

- Subproject 1: Development of strategies to control the rice sheath blight disease caused by the fugal pathogen *Rhizoctonia solani*
- Subproject 2: Analysis of transgenic rice expressing heterologous heat tolerance gene
- Subproject 3: Exploration of phosphate transport system to improve phosphorus use efficiency in rice
- Subproject 4: Improvement of nitrogen use efficiency in rice under climate change
- Subproject 5: Biofortification of metal micronutrients in rice
- Subproject 6: Generation of rice cultivars with improved nitrogen utilization

Main Results to Date

Sheath blight caused by *R. solani* is a highly destructive rice disease affecting many places across the globe. The typical symptoms of this disease are irregular oval lesions with grayish and dark-brown margins on rice sheaths and leaf blades. To date, no rice varieties with effective resistance to *R. solani* have been discovered. Certain rice varieties have been identified as having tolerance or partial resistance, which was thought to be regulated by polygenic or quantitative loci (QTLs). By using improved microchamber inoculation, two mutant lines (ML965 and ML953) with stable SB resistant response were isolated from the IR64 mutant pool. Our achievements are as follows: we have (1) established a reliable experimental platform for evaluating the SB response of plants; (2) screened SB resistant lines from the IR64 mutant pool and obtained several resistant and susceptible SB lines; (3) crossed the SB resistant ML965 with the susceptible Pi Kan Tao (PKT); (4) developed populations of PKT/ML965 F_1, F_2, and BC_1 and evaluated their SB resistance response at both the seedling and adult stages; and (5) identified the polymorphic markers between parents and developed a reliable genotyping system. In 2019, to breed an SB resistant line, the project was conducted comprising the following steps: (1) genetic analysis, (2) linkage analysis and QTL mapping, and (3) introduction of the SB resistance of mutants into elite Taiwanese rice lines. The project's progress has been as expected. Our results will provide a basis for improving the sheath blight disease resistance of rice.

Biocontrol agents against *R. solani* are required. We have identified a bacterium, designated ASB, that has strong antagonistic activity against *R. solani*. ASB inhibits the sclerotial germination of *R. solani* on potato dextrose agar and lesion development on detached rice leaves. On the basis of the phylogenetic analysis of 16S rDNA and *gyrB* sequences, ASB was identified as *Bacillus amyloliquefaciens.* To further investigate the antifungal substance, a cultural broth of ASB or PMB01, a commercial biopesticide, was extracted using butanol. The crude extracts of ASB exhibited significantly higher anti-*R. solani* activity than the crude extracts of PMB01 did. After analysis of the crude extract using liquid chromatography electrospray ionization tandem mass spectrometry, three groups of cyclic lipopeptides were discovered: iturin, fengycin, and surfactin. The iturin and fengycin standards had relatively high inhibitory activity against *R. solani* and were used to establish calibration curves. After quantification, crude extracts of ASB were found to contain significantly higher levels of iturin and fengycin than crude extracts of PMB01 did. In both the pot test and filed test, ASB could reduce the disease symptoms of rice caused by *R. solani.* These results indicate that ASB is a potential biocontrol agent for preventing infection of *R. solani* and controlling sheath blight disease in rice.

To reinforce the thermotolerance of rice plants, we transformed a heat-stress-related gene, *AtHSFA2,* into rice. Three independent homozygous transgenic rice lines were differentially obtained. Expression of the transgene resulted in upregulation of the endogenous heat-stress-related genes—such as HSP101, HSP90-1, HSA32, and sHSP16.9C—at normal and mild heat stress (28°C and 37°C) conditions, indicating a positive regulatory effect of AtHSFA2 in rice. However, at an extremely high temperature (42°C), *AtHSFA2* expression suppressed the transcript levels of some of these genes, indicating a negative regulatory effect of AtHSFA2 under this condition. Physiological analysis revealed that overexpressing *AtHSFA2* increased the basal, short-term, and long-term acquired thermotolerance.

Phosphorus is an essential plant nutrient and acquired by phosphate (P_i) transporters. We investigated the role of rice P_i transporters during the reproductive development of rice and their effect on rice production. First, we demonstrated that the abnormal accumulation of cellular P_i affects rice yield, as indicated by seed setting, seed number, and seed dry weight. A high accumulation of cellular P_i results in low phosphorus use efficiency and is deleterious to rice yield. We identified two follower-specific P_i transporters, *OsPT7* and *OsPT12,* the expression of which is coordinated with pollen development. Furthermore, we discovered that P_i acquisition is controlled by P_i-upregulated *OsNLA1* encoding a ubiquitin E3 ligase, which directs the degradation of several rice P_i transporters, such as OsPT1, 2, 4, 7, 8, and 12. *OsNLA1* is actively expressed throughout the development of rice, including in rice's reproductive organs, and its expression is regulated by an upstream open reading frame in response to P_i availability. The disruption of *OsNLA1* not only resulted in increased P_i uptake from roots but also impaired pollen development and reduced grain production (Figure 1), suggesting a close association between P_i homeostasis and pollen viability. This study highlights the importance of P_i transporters and their regulation in controlling P_i acquisition, translocation, and reproductive success.

For nitrogen utilization, we have identified two transcription factor genes, *ZOS5-02 (Os05g0114400)* and *bHLH35 (Os04g0301500),* for which expression is induced by nitrogen treatment. We used knockout mutants and overexpression lines to investigate the functions of *ZOS5-02* and *bHLH35.* The *zos5-02* CRISPR knockout mutants were found to be shorter than the wild type is when grown in hydroponic solution containing NH_4NO_3 or Gln as the N source; this indicated a positive regulatory function of *ZOS5-02* in nitrogen utilization. We have obtained homozygous mutants and overexpression lines for *bHLH35.* Characterization of these plants is currently in progress.

In the first approach, we generated a chimeric hyperactive nitrate transporter NC4N driven by *NRT1.7* promoter; this transporter facilitates main NC4N expression in source leaves. We demonstrated that source-to-sink N remobilization was enhanced in the *NRT1.7p::NC4N::3'* transgenic Arabidopsis at both the vegetative and reproductive stages. Moreover, *NRT1.7p::NC4N::3'* transgenic Arabidopsis and tobacco exhibited improved growth and seed production. Therefore, we generated *NRT1.7p::NC4N::3'* transgenic rice and performed a field trial under the condition of 120 kg N/ha. Compared with that for the TNG67 control, the panicle number was 12% and 8% higher for the transgenic lines Q-5 and V-2, respectively (Fig 2A); furthermore, the grain yield was 9% and 3% higher (Fig. 2B). The findings suggested that expressing NC4N to energize nitrate remobilization is a feasible approach to improving the nitrogen use efficiency (NUE) and grain yield in rice.

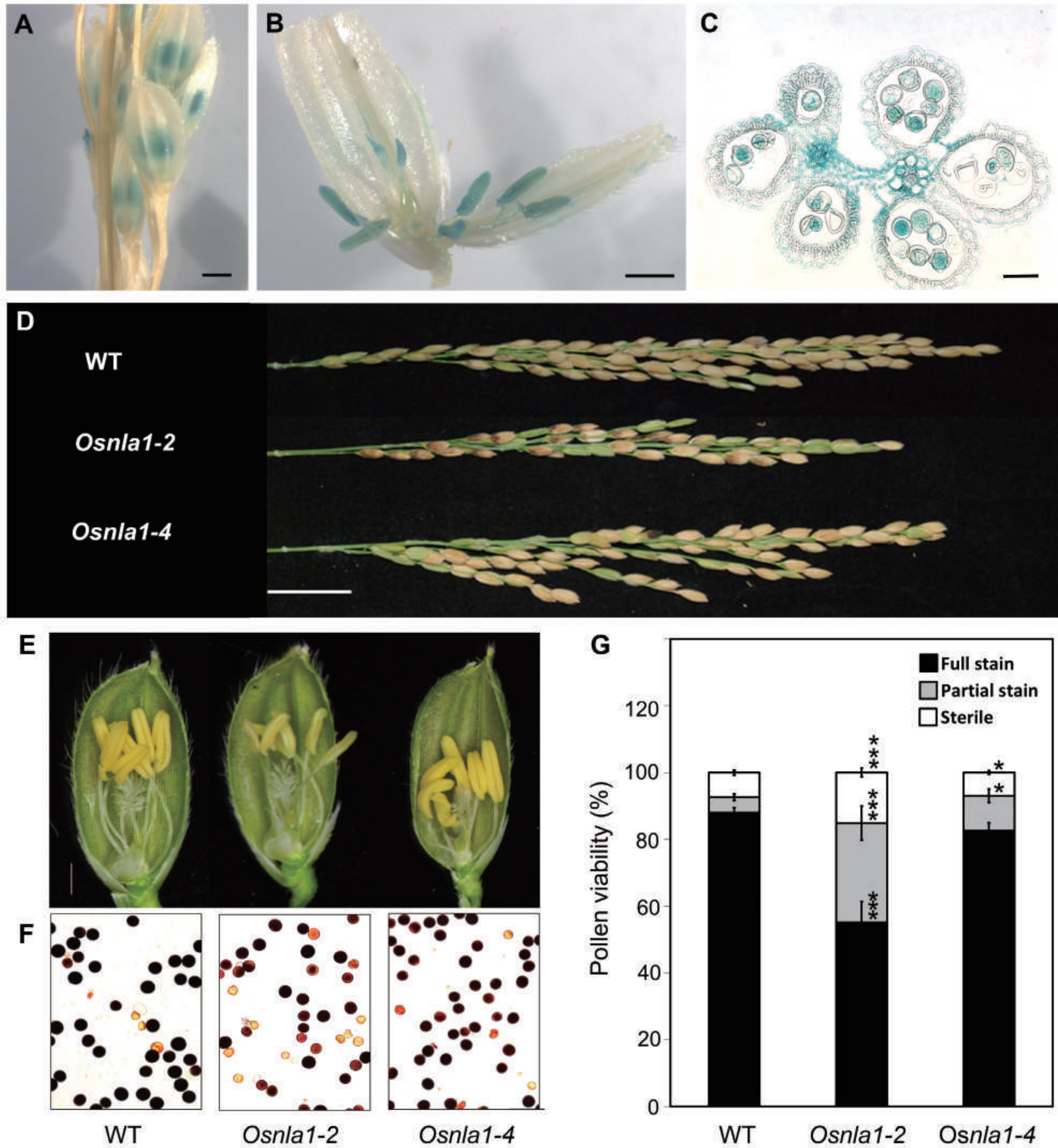

Fig. 1. OsNLA1 is expressed in reproductive organs and required for pollen viability and grain production.

Promoter activity of OsNLA1 in panicle (A, Bar = 2 mm), spikelet (B, Bar = 1 mm) and cross section of anther (C, Bar = 50 μm). Panicles of the WT and osnla mutants at grain maturity stage (D, Bar = 2 cm). Spikelets of the WT and osnla mutants at one day before anthesis (E, Bar = 1 mm). Pollen viability assay determined by starch staining (F). The percentage of each category was quantitated as shown in the bar chart (G). Standard errors refer to 4 biological replicates. Asterisks indicate a statistically significant difference from WT. ***, $P < 0.01$; *, $P < 0.1$.

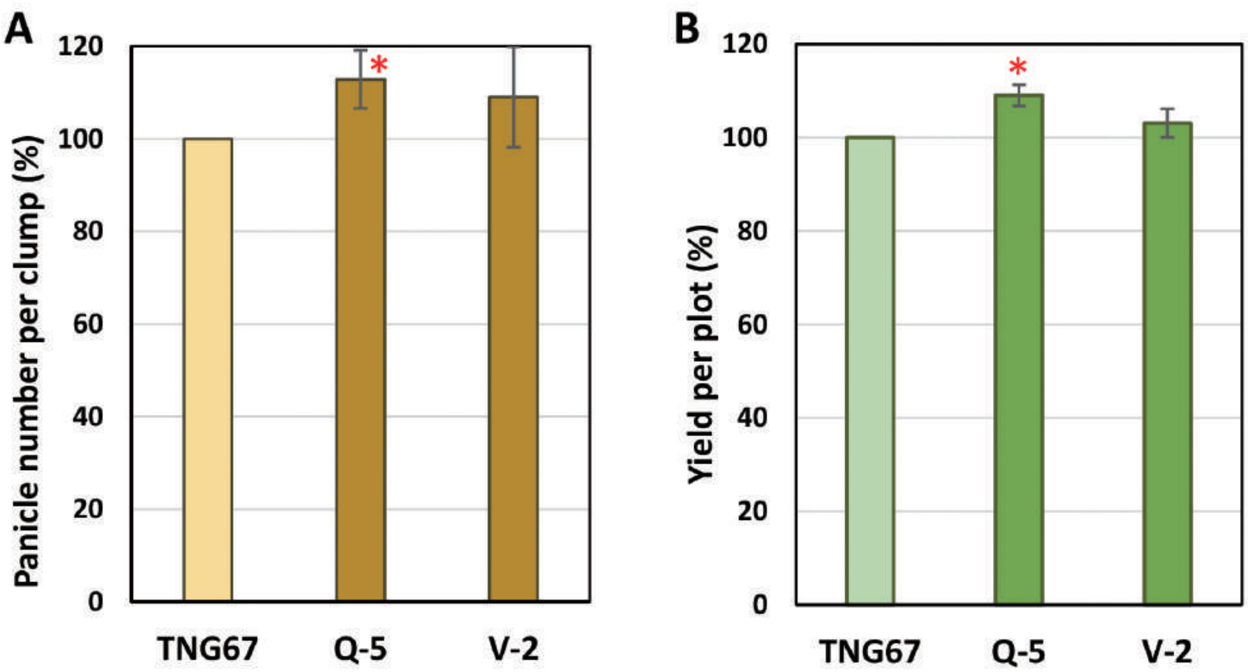

Fig. 2. Expression of NRT1.7p::NC4N::3′ improves grain yield of transgenic rice.

(A) Panicle number per clump and (B) grain yield per plot of TNG67 and transgenic lines Q-5 and V-2. Values are mean ± s.d. of 3 seasons. *, significant difference (p<0.05) between the transgenic lines and control (TNG67).

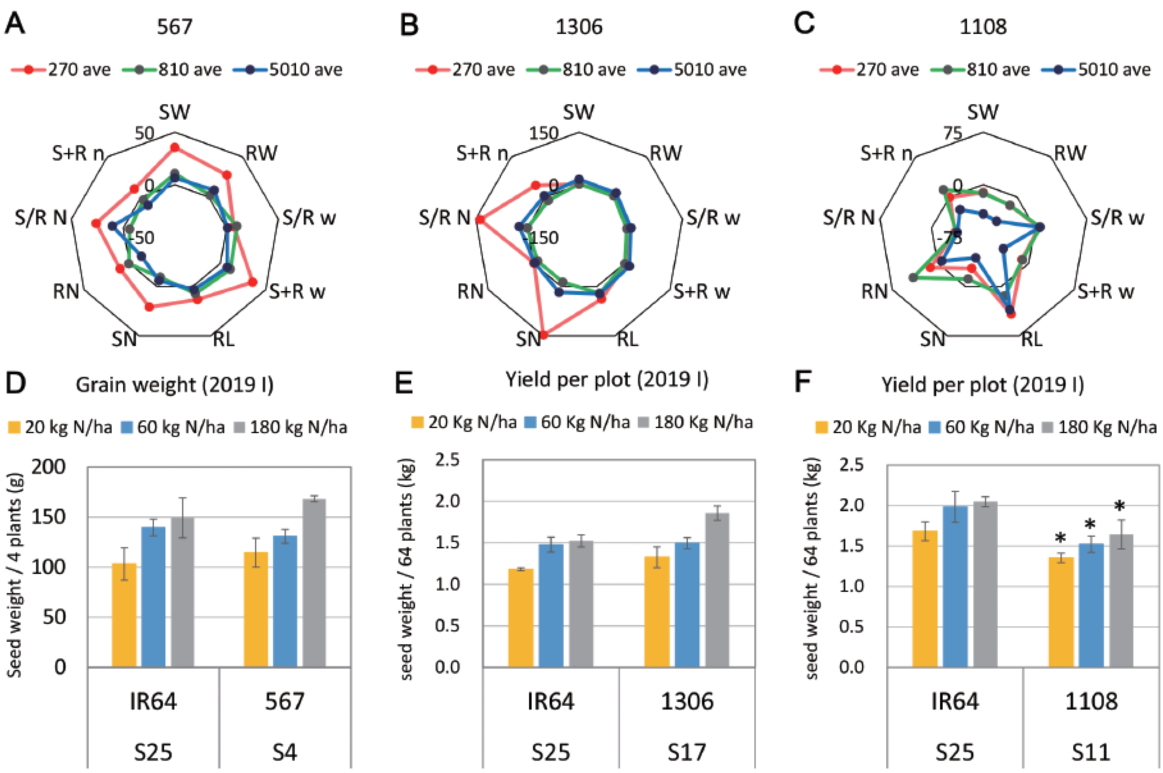

Fig. 3. The N-dependent phenotypes of mutants.

(A) Improve rate of #567 hydroponic traits under low, medium and high nitrogen. (B) Improve rate of #1306. (C) Improve rate of #1108. SW: shoot weight; RW: root weight; S/R W: shoot/root weight; S+R W: shoot + root weight; RL: root length; SN: shoot nitrate; RN: root nitrate; S/R N: shoot/root nitrate; S+R N: shoot + root nitrate. (D) #567 Grain weight. (E) #1306 Yield per plot (64 plants). (F) #1108 Yield per plot (64 plants). * indicates significant difference from WT. p<0.05.

Additionally, we screened N-related mutants in an IR64 mutant pool, which was developed using sodium azide. In a hydroponic system and field trial, we obtained three mutants (#567, #1306, and #1108) that had a N-dependent growth and yield phenotype. In the hydroponic system, all traits were enhanced in #567 under low N conditions (Fig 3A), suggesting that #567 had higher NUE. In #1306, considerable nitrate accumulated in the shoots under the low N condition (Fig 3B). As illustrated in Figure 2B, #1108 exhibited more significant defects under high N than low N (Fig 3C). In the field trial, #567 and #1306 were found to increase the yield under the high N condition (Fig 3D, E). By contrast, #1108 exhibited lower yield than the wild type did (Fig 3F). These findings suggested that these lines are nitrogen responsive and have potential in the investigation of the regulators crucial to improving rice NUE.

Iron and zinc deficiency affect more than half the human population. As a remedy, the biofortification of staple crops to enrich our often-consumed foods with micronutrients is feasible, being achievable through both modern biotechnology and traditional breeding practices. We screened thousands of sodium-azide-mutated rice lines, including Japonica (TNG67) and Indica (IR64), and obtained mutants with increased Zn or Fe in rice grains. Interestingly, all identified mutants were from the IR64 mutant pool. In the screening, we discovered that the average Zn and Fe levels were approximately 20% higher in TNG67 than in IR64. We have identified and confirmed the high Zn or Fe phenotype of nine IR64 lines after 2–3 generations have been grown in the field (Table 1). In addition, the overexpression of a nicotianamine synthase from the Zn hyperaccumulator *Arabidopsis halleri* has been found to increase iron and zinc accumulation in rice grains.

Future Research Plan

To develop ASB as a biocontrol agent against *R. solani,* we will perform a large-scale field trial to test its efficacy. In addition, we will complete the linkage analysis and QTL mapping as well as introduce the *R. solani* resistance gene into Taiwanese elite lines.

In the phosphorus use efficiency project, we are currently examining RNAi rice lines, in which another-specific expression of OsPT7 and OsPT12 P_i transporters is suppressed. This will enable us to understand the role of P_i transport during pollen development.

In the NUE project, we will optimize the NC4N expression in transgenic rice plants by selecting a rice endogenous promoter for further boosting the yield in a field trial. Regarding the sodium-azide-mutagenized IR64 candidate lines, we will confirm the traits of these lines in a field trial and perform genetic mapping to elucidate the molecular mechanisms and identify the genes associated with the NUE.

Table 1. High Zn, Fe in grain of mutant lines in preliminary (1st) and secondary (2nd) screening.

mutant lines	Zn (1st/2nd)	Fe (1st/2nd)
121-164	++/+	+/+
121-315	++/++	++/n
121-377	++/+	
121-515	+/+	+/+
121-788		++/+
121-793	n/++	++/++
121-878	n/n	n/+
121N071	+/++	+/+
121N226		++/+

+, 1.5 times more than in wild-type. ++: 2 times more than in wild type. n: same as in wild type. WT grain with average Zn 32 mg/kg, Fe 12 mg/kg

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Project Director: **Ming-Che Shih**

Dr. Ming-Che Shih is a Distinguished Research Fellow of the Agricultural Biotechnology Research Center. His research focuses on plant responses to environmental stresses, application of omics technologies in sustainable agriculture and agricultural biotechnology, and exploring microbial genomes for biocontrol agents against plant pathogens.

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Development of Next-generation Sustainable Photovoltaic Energy

Project starting year: 2017

Hosting Institute: Institute of Atomic and Molecular Sciences, Academia Sinica

Research Objectives

Develop new-generation photovoltaic energy

Main Results to Date

In The Taiwan Declaration on Sustainable Development promulgated by the National Council for Sustainable Development Network in Taiwan, developing low-carbon energy is considered a critical for sustainable development and energy security. Currently, renewable energy in Taiwan only accounts for <10% of total energy production. The development of renewable energy has therefore become crucial for achieving sustainable development and energy security in Taiwan. Among the known renewable energy sources, solar energy can be harvested using the photovoltaic effect to convert photons into electricity. In addition, recycling light energy from artificial lighting is essential. Artificial lighting consumes approximately 19% of global electricity and is not recycled; the photovoltaic effect is the most feasible approach to achieve this. Photovoltaic cells used for this purpose require three characteristics: (1) tunable light-harvesting wavelength range, (2) flexibility to fit the lighting environment, and (3) high conversion efficiency under weak light. Next-generation photovoltaic cells have these properties and are therefore more suitable than conventional Si photovoltaic cells for recycling artificial light energy. The aim of this project is to develop three next-generation photovoltaic technologies (polymer, perovskite, and metal chalcogenide photovoltaics) and to assess their sustainability through a lifecycle analysis.

For polymer photovoltaics, a new low-bandgap polymer, namely a benzo(1,2-b:4,5-b′)dithiophene-based low-bandgap polymer (pBCN; Figure 1A), was developed, with a power conversion efficiency (PCE) of >6%. Polymer solar cells are fabricated using shear-induced crystallization and additives to control the ordered aggregation of polymers (Figure 1B). For perovskite photovoltaics, a benzo[ghi]-perylenetriimide (BPTI) monomer and its twisted dimer *t*-BPTI (Figure 2A) were developed as a new electron-transport layer material in inverted perovskite cells (PCE: 10.73%); a lead-free perovskite cell was developed based on $(CH_3NH_3)_3Sb_2I_9$ (Figure 2B), with a PCE of 2.77%; and an all-vacuum-processing fabrication of perovskite cells was developed (Figure 2C), with a PCE of approximately 30% under ambient light conditiond. For metal chalcogenide photovoltaics, a fabrication process based on multilayer precursors was developed to produce high-quality CZTSSe thin films (Figure 3A), and electron-selective contact was improved through the insertion of interfacial layers of alkali metal fluoride (Figure 3B). The highest PCE achieved was 11.5%. Furthermore, an artificial neural network–based potential energy model was developed to predict defects in growing perovskite and CZTSSe materials (Figure 4A), and in situ optical spectroscopy was conducted to elucidate the polymer aggregation process (Figure 4B). Finally, a sheet-to-sheet large-area slot-die coating technique for large-area organic solar cells was developed. The thus-fabricated cells yielded a PCE of 6% for a device area of 1 × 0.3 cm^2 and 5% for a device area of 1 × 5 cm^2 (Figure 5).

In addition to these five subprojects, we also performed CO_2 emission analysis of four photovoltaic systems (wet perovskite, dry perovskite, CZTSSe, and polymer.) The structure of the wet perovskite cell is glass/ITO/PEDOT:PSS/perovskite/PCBM/PEI/Ag, where PEDOT:PSS is poly(3,4-ethylenedioxythiophene) polystyrene sulfonate and PEI is polyethyleneimine. The structure of the dry perovskite cell is glass/ITO/C_{60}/perovskite/TAPC/MoO_3/Ag, where TAPC is 4,4′-cyclohexylidenebis[N,N-bis(4-methylphenyl) benzenamine]. The structure of the metal chalcogenide cell is Mo glass/CZTSSe/CdS/ZnO/ITO/MgF_2/Ag. The structure of the inverted polymer cell is glass/ITO/ZnO/pBCN:$PC_{61}BM$/MoO_3/Ag, in which the active layer is a bulk heterojunction of mixed pBCN and $PC_{61}BM$ that is [6,6]-phenyl-C_{61}-butyric acid methyl ester. The CO_2 emission per cell and per unit area during material acquisition and device fabrication (Figure 6) indicate that among the four next-generation photovoltaic cells, the production of CZTSSe cells generated the highest CO_2 emission. One reason for this is the involvement of multiple vapor-deposition and annealing processes. Notably, the CO_2 emission of the perovskite cell produced by the all vapor–deposition process (dry perovskite cell), was comparable to that produced by the solution process (wet perovskite cell). These data should help policymakers and stakeholders understand the sustainability aspects of the four typical next-generation photovoltaic technologies and consider these aspects during policymaking when promoting these photovoltaic technologies in the future.

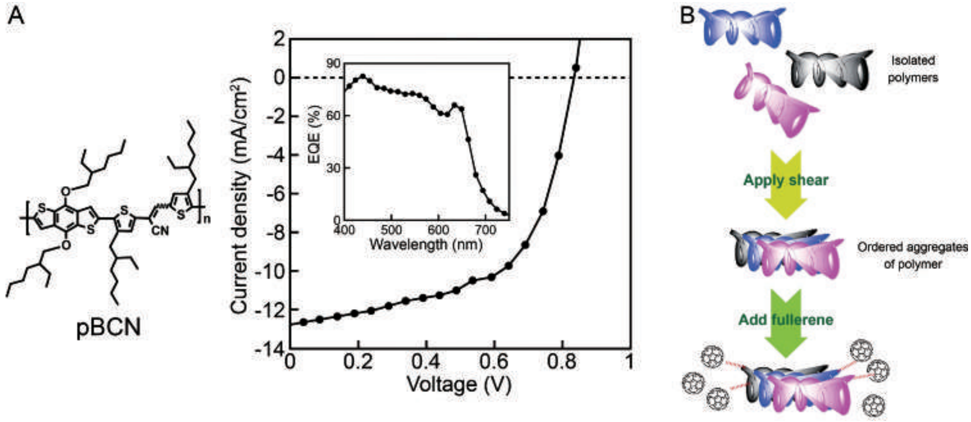

Fig. 1. (A) Molecular structure of pBCN and current density-voltage and equivalent quantum efficiency (EQE) curves of bulk heterojunction pBCN:$PC_{71}BM$ solar cell; (B) processing steps of shear-induced ordered packing of polymers and hydrogen bond (red dotted lines) that facilitates mixing with fullerene derivatives.

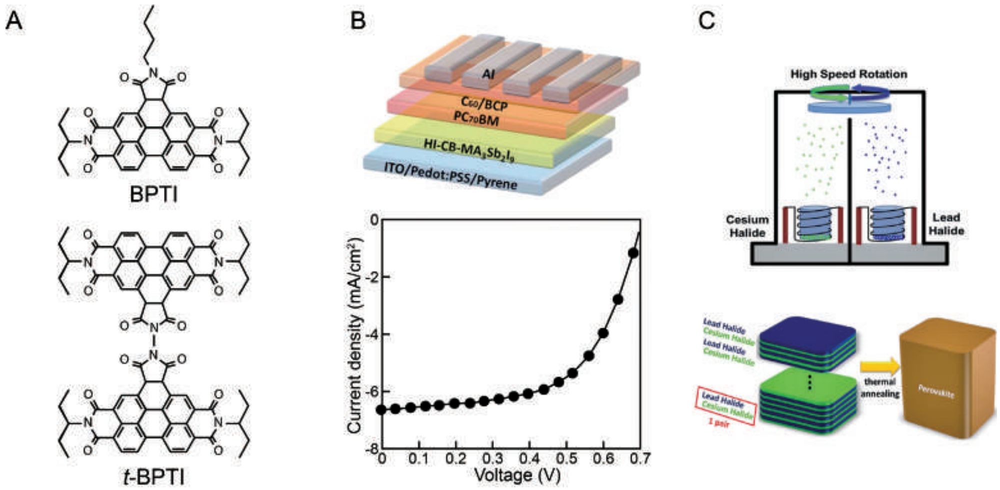

Fig. 2. (A) Molecular structures of BPTI and t-BPTI; (B) device structure of perovskite cell made with lead-free $MA_3Sb_2I_9$ and its current density-voltage curve; (C) growth of $CsPbI_3$ with multilayer vacuum deposition followed by thermal annealing.

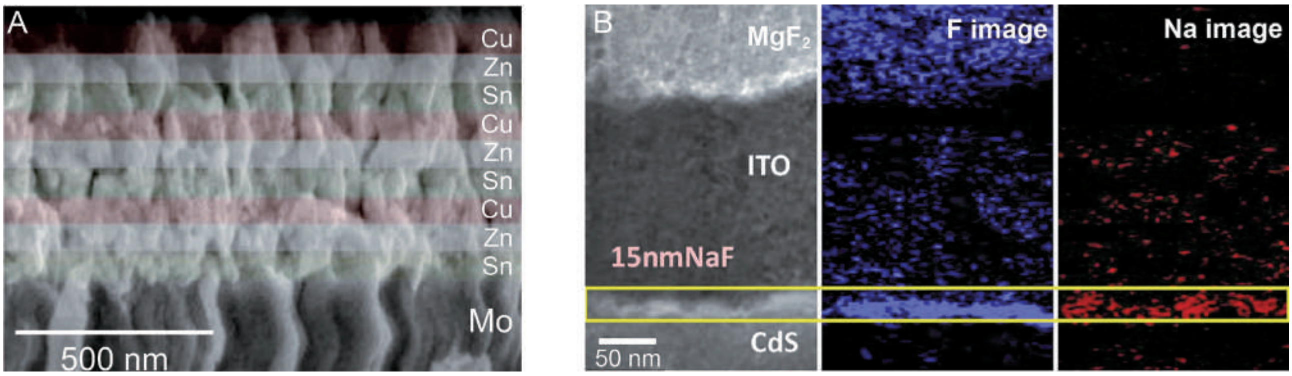

Fig. 3. Improvement strategies of CZTSSe cells: (A) synthesis of high-quality CZTSSe thin film by enhancing the inter-diffusion of Cu, Zn, and Sn in multi-layer structure and (B) introducing NaF interlayer to enhance electron contact.

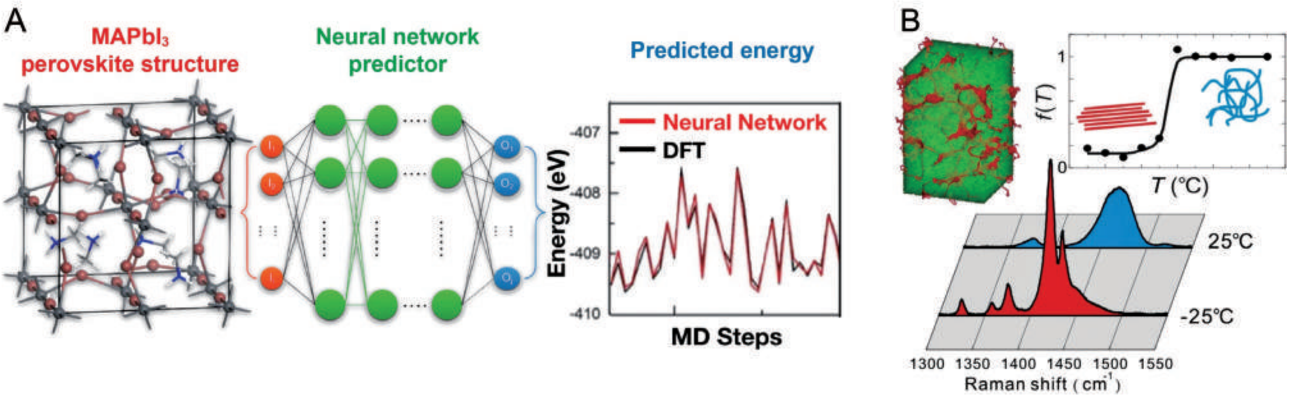

Fig. 4. In-depth study effort: (A) neural network potential model for atomistic simulation of $MAPbI_3$ perovskite with high fidelity to density function theory (DFT) calculations; (B) evolution of P3HT aggregation investigated by Raman spectroscopy and multi-scale simulation.

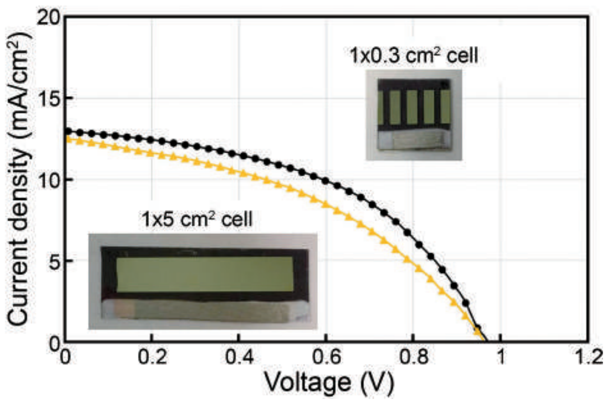

Fig. 5 Current density-voltage curves of slot-die coated SMOSCs with cell areas of 1×0.3 (black circles) and 1×5 cm^2 (yellow triangles).

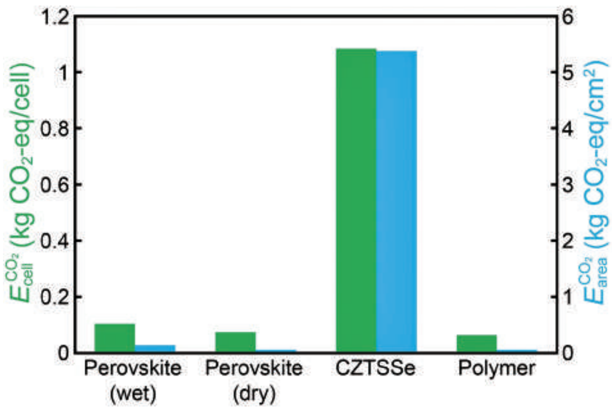

Fig. 6 Estimated CO_2 emission per cell ($E_{cell}^{CO_2}$, green bars) and per unit area ($E_{area}^{CO_2}$, blue bars) of perovskite (wet), perovskite (dry), CZTSSe and polymer cells during material acquisition and device fabrication.

Future Research Plan

Develop next-generation sustainable photovoltaics for indoor and healthcare applications.

With Taiwan's future technological development of IoT and healthcare applications, the current status of next-generation photovoltaic technology, and our team's research competencies, we plan to develop next-generation sustainable photovoltaics for indoor and healthcare applications. The whole program is divided into five subprojects: (1) development of high-performance flexible all-polymer solar cells with long-term device stability for potential energy-autonomous electronics, (2) development of dry-processed organic and perovskite photovoltaics for indoor applications, (3) development of next-generation no-toxic/earth-abundant metal chalcogenide-based thin-film solar cells for applications in indoor energy-autonomous electronics, (4) conducting fundamental studies of next-generation photovoltaic materials and devices, and (5) development of mass-producible flexible large-area organic solar cell modules for integration.

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Project Director:

Chin-Ti Chen, Research Fellow

Dr. Chen received his Ph.D. in Chemistry from University of Illinois at Urbana-Champaign in 1992. Dr. Chen worked as postdoctoral research fellow at California Institute of Technology form 1992 to 1995. In year 1995, Dr. Chen joined the Institute of Chemistry, Academia Sinica as an assistant research fellow, was promoted to associate research fellow in 2000, and research fellow in 2003. His research interests include organic materials for optoelectronics applications, including perovskite solar cells (PVSCs), organic photovoltaics (OPVs), and organic light-emitting diodes (OLEDs). He has served Journal of the Chinese Chemical Society as associate editor since 2014, and Sustainable Chemical Science and Technology Program of TIGP, Academia Sinica as coordinator since 2013.

Juen-Kai Wang, Research Fellow

Dr. Wang received his Ph.D. in Applied Physics from Harvard University in 1992. Dr. Wang joined Center for Condensed Matter Sciences, National Taiwan University in 1994 and was jointly appointed by Institute of Atomic and Molecular Sciences, Academia Sinica in 2003. His current research interests are surface-enhanced Raman spectroscopy, nanometer-scale optical spectroscopy, and steady-state and time-resolved optical spectroscopy. Dr. Wang was granted Executive Yuan Award for Outstanding Contributions in Science and Technology in 2009 and Nano-Tech Award bestowed by Ministry of Economic Affairs in 2010.

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International Program

The Center for Sustainability Science (CSS) hosts Taiwan's branch office of the following two international cooperation programs in an attempt to bridging Taiwan's researchers with the global sustainability research community and to building capacity of transdisciplinary sustainability science researches.

IRDR ICoE-Taipei

The Integrated Research on Disaster Risk (IRDR) International Centre of Excellence in Taipei (ICoE-Taipei) serves as an international platform of disaster risk reduction for building capacity and facilitating collaborative research in the Asia-Pacific region. In 2019, IRDR ICoE-Taipei organized four international training camps (Advanced Institutes, AI), awarded and managed AI Seed Grants, and actively participated in other international networking meetings. For a complete introduction of 2019 achievements and future plan of this program, please read Page 32-39.

Future Earth Taipei

Following Future Earth's vision and plan, Future Earth Taipei dedicates to promote multidisciplinary, solution-oriented, international collaborative, and stakeholder-engaged sustainability researches. In order to accelerate the transformation toward a sustainable world, Future Earth emphasizes on the linkage between knowledge and action for significant sustainability issues. In 2019, Future Earth Taipei officially launched Working Groups corresponding to seven issues, organized a number of international and domestic conferences and activities, and actively participated in the operation of Future Earth. For a complete introduction of 2019 achievements and future plan of this program, please read Page 40-48.

Follow IRDR ICoE-Taipei

Follow Future Earth Taipei

Integrated Research on Disaster Risk (IRDR)

International Centre of Excellence in Taipei (ICoE-Taipei)

INTRODUCTION

With the agreement of the International Science Council (ISC), Academia Sinica established IRDR ICoE-Taipei, the very first International Centre of Excellence (ICoE) for the Integrated Research on Disaster Risk (IRDR). The Center for Sustainability Science (CSS) hosts this program office. The main goal of the IRDR ICoE-Taipei is to serve as an international platform for conducting multidisciplinary disaster risk reduction (DRR) research that integrates both natural and social scientific perspectives. The tasks include increasing the capacity of countries in the Asia-Pacific region, facilitating research programs, and establishing a platform for effective exchange among scientists, engineers, government officers, and stakeholders.

IRDR ICoE-Taipei strives to increase the depth of international cooperation between researchers, policymakers, and stakeholders, thereby enhancing the international impact of research from Taiwan. The internationalization strategy includes the organization of training courses and funding lines that are designed to stimulate cross-country and cross-disciplinary exchange mainly in countries in the Global South.

WHAT HAS BEEN ACCOMPLISHED in 2019

The tasks to be accomplished in 2019 were significant and challenging. In 2019, IRDR ICoE-Taipei accomplished the following: 1) organized four international training camps to increase regional DRR capacity, with these camps engaging 164 young and senior professionals; 2) solicited applications for Seed Grants and awarded US$150,000 to 10 out of 17 competing proposals; 3) continued to track 9 awarded Seed Grant projects; 4) funded the visit of three established international scholars in the field of sustainability sciences to Taiwan and Academia Sinica; 5) participated in five IRDR-related international meetings; and 6) organized an International Scientific Advisory Board meeting. In the years ahead, in addition to continue working on these aforementioned tasks, IRDR ICoE-Taipei is anticipating the establishment of more outreach connections, especially connections to other ICoEs in the Asia-Pacific region.

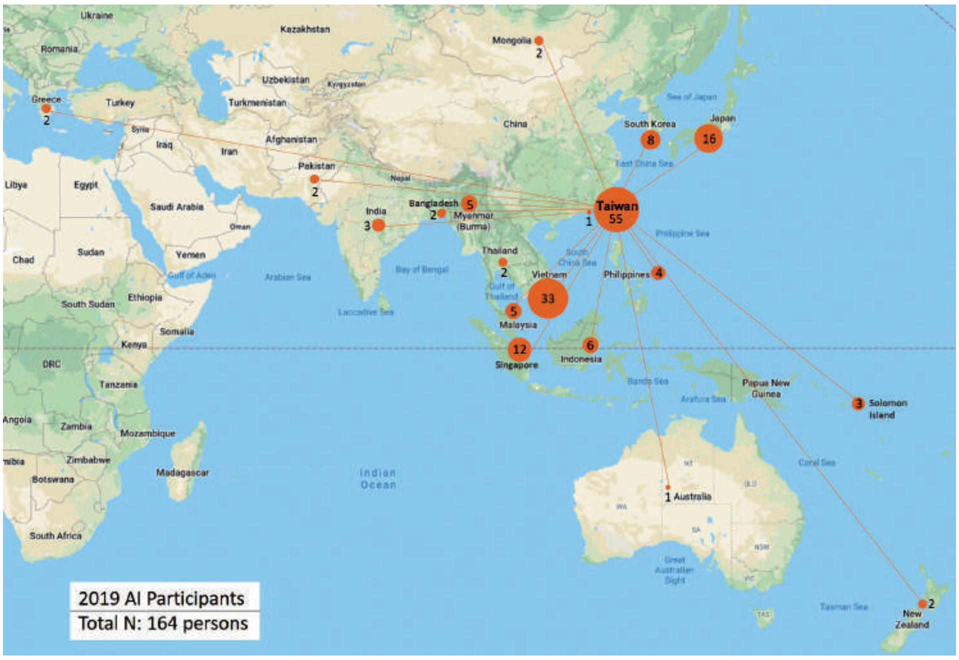


Fig. 1. IRDR ICoE-Taipei Advantaged Institutes & Training workshops participants' networks

REGIONAL CAPACITY BUILDING

Since 2010, IRDR ICoE-Taipei has provided more IRDR-themed training opportunities to young scientists and practitioners worldwide. In 2019, IRDR ICoE-Taipei continued to pursue its goal of capacity building for the Asia-Pacific region by focusing on cross-country and cross-disciplinary approaches. Four training camps were held, which involved a total of 164 participants, including students, scientists, engineers, and government officers. The four training camps were as follows:

1) *Training Course on Earthquake Early Warning system in East Asia, TC-EEWSEA, March 2019;*
2) *Advanced Institute -Training Course on Landslide Investigations and Hazards Mitigation, AI-TCLIHM, July 2019, Hanoi, Vietnam;*
3) *Advanced Institute on Health Investigation and Air Sensing for Asian Pollution, AI on Hi-ASAP, September 2019;*
4) *Advanced Institute on Asian Consortium of Volcanology, AI-ACV, October 2019.*

The ***Training Course on Earthquake Early Warning Systems in East Asia*** was organized by IRDR ICoE-Taipei in partnership with the ISC Regional Office for Asia and the Pacific (ISC ROAP), Taiwan Earthquake Research Center (TEC), Central Weather Bureau (CWB), National Center for Research on Earthquake Engineering (NCREE), San Lien Technology Corp, and National Science and Technology Center for Disaster Reduction (NCDR). It was held from March 25 to 28. The purpose of the course was to share experience regarding the operation of the P-Alert system. Participants and lecturers from more than 10 countries were invited to join this training camp. In this advanced course, nine lecturers from Taiwan taught participants the theory, techniques, and practices of erthquake early warning. Participants from different countries also shared their experiences of early warning operation with each other. IRDR ICoE-Taipei strives to include several policymakers and stakeholders in training events, and 26 participants were selected because of their location, affiliation, and professional background. These participants were from Greece, India, Indonesia, Myanmar, New Zealand, Singapore, the Solomon Islands, South Korea, Taiwan, and Vietnam.

Fig. 2. Lecture of earthquake early warning system

Fig. 3. Visit to the Central Weather Bureau for the forecasting and early warning system

The ***Advanced Institute-Training Course on Landslide Investigations and Hazard Mitigation*** event was co-organized by IRDR ICoE-Taipei, Hanoi University of Mining and Geology, the ISC ROAP, and the Landslide Research Teams from National Central University and Academia Sinica. The event was held in Vietnam from July 20 to 25. As one of the most tectonically active regions, Southeast Asia has had many landslides. Therefore, the sharing of experiences of landslide investigations and hazard evaluation should be institutionalized through this platform.

Fig. 4. Fieldtrip for landslide observation in Halong Bay

This training course comprised a series of comprehensive lectures, practices, and a field trip, which were intended to provide fundamental knowledge about landslides for the mitigation of hazards and the corresponding loss of life and property. This course focused on disaster monitoring, forecast, and warning for landslide-related hazards and conducted hands-on practice sessions and field trips. Thirteen lecturers from Taiwan, Vietnam, and Japan were involved, and 27 academic and practical personnel from government, academia, and graduate institutes were selected to participate in the training exchange camp.

Fig. 5. Lecture of real-time land quake monitoring

The ***Advanced Institute on Health Investigation and Air Sensing for Asian Pollution (AI on Hi-ASAP)*** was organized by IRDR ICoE-Taipei in partnership with the ISC ROAP and held in Taipei on September 2 to 6, 2019. Air pollutants, especially particulate matter with aerodynamic diameter equal to or less than 2.5 µm (PM2.5), constitute a significant risk to human health. Millions of deaths worldwide have been attributable to PM2.5, which is a human carcinogen. Especially in Asia, rapid economic growth has taken its toll on human health; an estimated 2.2 million of the world's 7 million premature deaths each year from air pollution are in the Asia-Pacific area (WHO, 2018). **New sensing technologies** for assessing the exposure sources and health impact of PM2.5 in Asia are urgently required to reduce the health risks posed by this human-made

* WHO. (2018). Mortality and burden of disease from ambient air pollution. Retrieved August 2, 2019, from https://www.who.int/gho/phe/outdoor_air_pollution/burden/en/

pollution disaster. Hi-ASAP is a regional transdisciplinary research initiative that has been developed under the umbrella of the International Global Atmospheric Chemistry project–Monsoon Asia and Oceania Networking Group. The main goal of Hi-ASAP is to provide scientific evidence supporting effective policy action to reduce air pollution levels, particularly PM2.5 pollution, in this region by employing newly developed and affordable sensing devices.

Eighteen lecturers from Taiwan, Hong Kong, Malaysia, Australia, and South Korea were involved in teaching research methods and leading the practice of air quality monitoring and human physiological measurement. A total of 22 young scientists from Bangladesh, Indonesia, Japan, Malaysia, Mongolia, Myanmar, Pakistan, the Philippines, Taiwan, Thailand, and Vietnam were selected to participate in the training camp. Additionally, a follow-up Seed Grant competition was planned to encourage potential cross-disciplinary research teams to research Hi-ASAP topics.

Fig. 6. Hands-on practices of air quality and human physiology measurement under different circumstances.

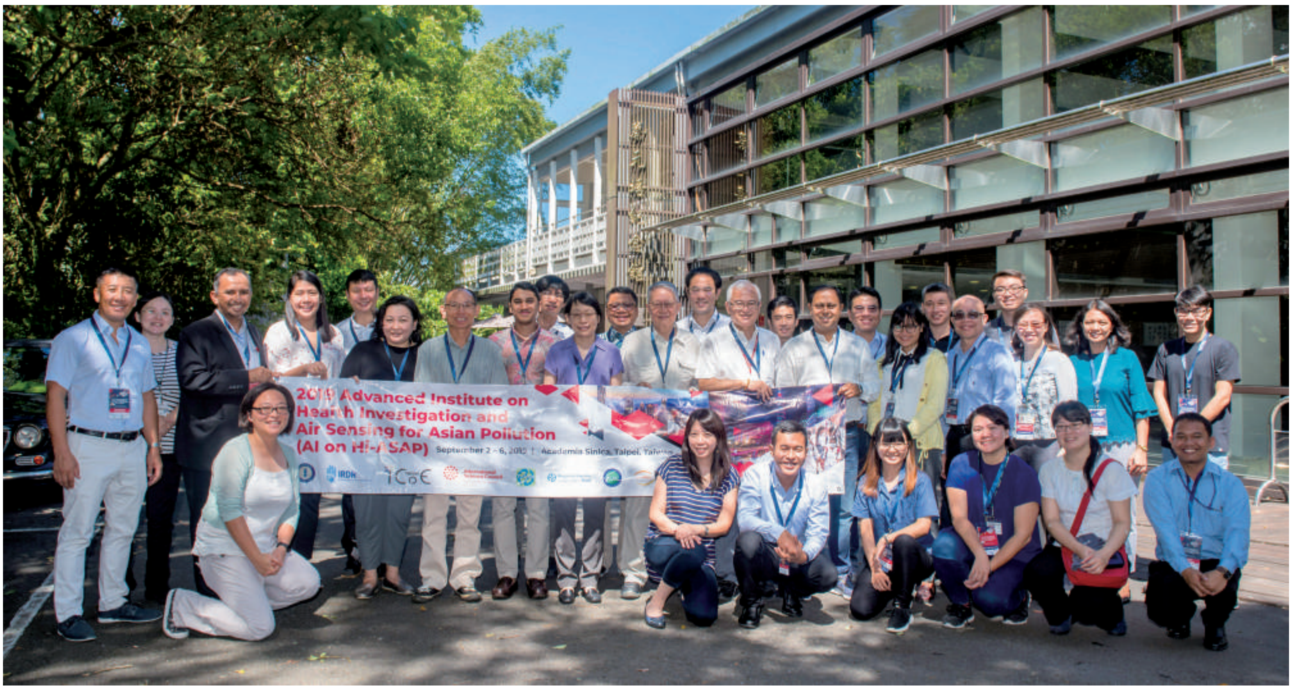


Fig. 7. AI on Hi-ASAP aims to build a framed platform for regional research collaboration.

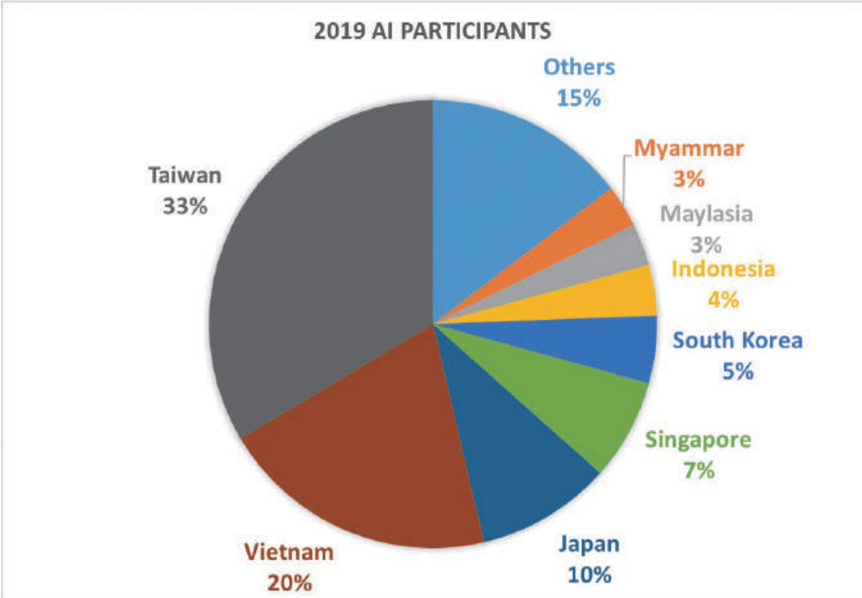
The ***Advanced Institute on the Asian Consortium of Volcanology (AI-ACV)*** was held from October 28 to November 2 and discussed phreatic eruptions and its hazard management. In partnership with the Volcanological Society of Japan, Earth Observatory of Singapore, and Tatun Volcano Observatory of Taiwan, IRDR ICoE-Taipei invited more than 40 young scientists to participate in this training camp. The Asia-Pacific region is susceptible to volcano-related disasters. The East Asia subregion is located along the "Pacific Ring of Fire," whereas Southeast Asia is located along the giant Sumatra subduction zone; these subregions are thus extremely susceptible to volcanic eruption. In 2016, Mt Aso in Japan erupted; in 2017, Mt Sinabung and Mt Agung in Indonesia erupted; and as recently as January 2018, Mt Mayon in the Philippines erupted. Other volcanoes in the region are also at risk of having a high-impact eruption.

The objective of the training course was to provide early career scientists with knowledge and skills. Participants, who were mainly volcanologists based in the Asia-Pacific region, shared their experiences and exchanged knowledge. The course focused on the interpretation of volcanic observation data; many aspects of such interpretation were covered, including geophysics, geochemistry, geology, and petrology. Both lecturers and early career scientists shared data and findings regarding active volcanoes. Group exercises and field trips were organized to facilitate discussion and provide hands-on experience. The participants were from Japan, Singapore, the Philippines, France, Spain, New Zealand, the United States, England, Indonesia, China, South Korea, and Taiwan.

Fig. 8. AI-ACV built an effective platform for interaction and collaboration of volcano eruption monitoring and hazard management.

Fig. 9. Group discussions and field trip of AI-ACV.

In conclusion, Training camps and courses organized by IRDR ICoE-Taipei in 2019 left a great impression on the 164 participants from 18 countries, and many participants were engaged in the follow-up thematic Seed Grant projects. Additionally, the success of these programs served as a frame for the creation of an international research network in the Asia-Pacific region. IRDR ICoE-Taipei has continued to increase the DRR capacity in the region.



Total N: 164 persons

Others (N<5)
Australia
Bangladesh
Greece
Hong Kong
India
Mongolia
New Zealand
Pakistan
Philippines
Solomon Islands
Thailand

Fig. 10. National distribution of the participants of AI/training courses.

REGIONAL RESEARCH COOPERATION

Considering the challenges that the Asia-Pacific region is facing, IRDR ICoE-Taipei has allocated most of its resources to the training and support of Asian-Pacific countries in the Global South and their conduct of DRR research. IRDR ICoE-Taipei encourages AI participants to cooperate across countries and disciplines. Therefore, IRDR ICoE-Taipei offers AI-follow-up Seed Grants, allocated through a rigorous review process. In 2019, 94% of Seed Grant applicants were from “New Southbound countries,” as defined in the Taiwanese government’s New Southbound Policy.

In 2019, three projects were launched: Seed Grants for the Advanced Institute–Landslide Risk Reduction Training School(AI-LRRTS), Training Course on Earthquake Hazard and Risk Assessment in East Asia(TC-EHRA), and AI on Hi-ASAP. The focus was on natural disasters and environmental change in the Asia-Pacific region. The topics covered include landslides, earthquakes, public health, air pollution, and risk assessment. A total of 17 competing proposals were received. More than 90% of the applicants were from New Southbound countries (Figures 11 and 13). Ten projects were approved, with US$150,000 in total research funds allocated.

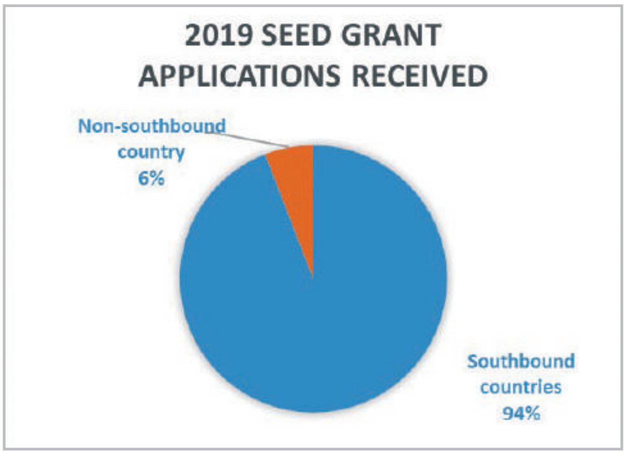


Fig. 11. Application for Seed Grant received in 2019.

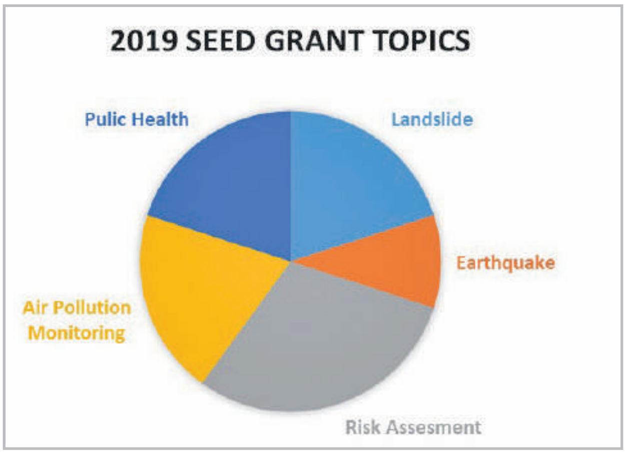


Fig. 12. Covered topics of Seed Grant in 2019.

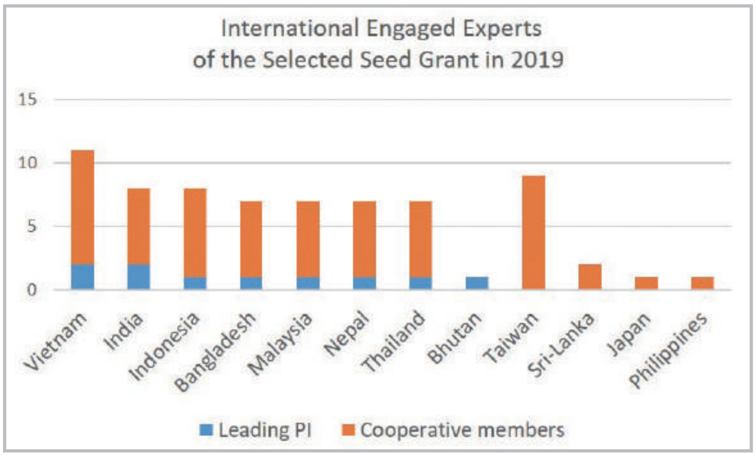


Fig. 13. Applications received in 2019.

The grant supported international and cross-disciplinary cooperation teams in the Asia-Pacific region. The grant applications were submitted by teams having a total of 91 experts from 15 countries, including 16 experts from Taiwan; these experts included scientists, government officers, and stakeholders. Such diverse background indicates that the Seed Grants have opened the view and vision for participants and impact of Taiwanese experts in the Asia-Pacific region.

In 2019, IRDR ICoE-Taipei continued to track six on-going Seed Grant projects that were launched in 2017 or 2018. The projects are associated with two previous AIs, namely the Advanced Institute on Disaster Risk Reduction with Systems Approach for Slow-Onset Climate Disasters on air pollution, sensors and big data (four projects) and on heat stress sensors and early warning and information technology (two projects).

NETWORKING

One of the tasks of IRDR ICoE-Taipei is to facilitate exchange between research institutes with respect to scholars, ideas, and information. IRDR ICoE-Taipei thus allocates resources to visiting scholars to share their experience and insight. From May 13 to 18, three internationally well-known marine climatologists were invited to visit Taiwan to participate in seminars and discussions. Professor Brian Hoskins of the United Kingdom, Professor Peter Bellwood of Australia, and Professor Gretta Pecl of Australia discussed issues pertaining to the marine and atmospheric environment from the perspective of international sustainable development.

INTERNATIONAL STRATEGY-MAKING ACTIVITY

ICoE-Taipei has actively participated in IRDR events and its annual Scientific Committee (SC) Meetings. On May 13, two members of ICoE-Taipei staff flew to Geneva to participate in the 21st IRDR SC meeting. In this meeting, IRDR ICoE-Taipei reported on implementation outcomes and discussed the regional cooperation links of IRDR units, which are planned for information sharing. From October 8–10, two members of staff went to Xiamen to participate in the 22nd IRDR SC meeting and report on the outcomes of IRDR ICoE-Taipei's implementation. By promoting our work, we increased the international visibility of IRDR ICoE-Taipei. In addition to reports and discussions of the implementation outcomes, the topics of this meeting included future IRDR plans and directions for next decade.

Fig. 14. 2019 Invited scholars after a seminar.

Fig. 15. The 21st IRDR SC Meeting, 13 May, Geneva.

Fig. 16. The 22nd IRDR SC Meeting, 8-10 October, Xiamen.

SPECIAL SESSION IN INTERNATIONAL CONFERENCE

One noteworthy event was the special session for the Regional Collaborative Research on Air Pollution Sensing and Health in Asia. This special session was held by IRDR ICoE-Taipei and Future Earth in the 16th Annual Meeting of the Asian Oceania Geosciences Society (AOGS) in Singapore from July 28 to August 3. The event was mostly attended by those who were previously awarded a Seed Grant on this topic. The presenters invited to this showcase were from the Philippines, Vietnam, and Indonesia and detailed their findings obtained from collaborating across countries and disciplines with support from IRDR ICoE-Taipei and DRR researches in the Asia-Pacific region. This session promoted IRDR ICoE-Taipei and offered participants an opportunity to learn from the experience and feedback given by other attendees, who were from many international organizations. Such reconnection with those who had participated will be the forthcoming emphasis of IRDR ICoE-Taipei.

ANNUAL ADVISORY BOARD MEETING

One final but crucial meeting was the annual Scientific Advisory Board (SAB) Meeting of IRDR ICoE-Taipei from December 4 to 6. The SAB meeting was held to gather feedback on ICoE-Taipei's plans and strategic direction. SAB members are from academia and reputable international organizations, with substantial experience in international collaboration on disasters and risk reduction. Two members retired at the end of 2019, and one new member was elected to the board, which now has eight members. In addition to the members, IRDR ICoE-Taipei invited John Handmer, chairman of the Scientific Committee of the Integrated Research on Disaster Risk (IRDR), and Charles Erkelens, Operations Director of the ISC, to provide valuable insights.

Fig. 17. Annual IRDR ICoE-Taipei SAB meeting.

FORTHCOMING 2020

In the following few years, in addition to the tasks described previously, IRDR ICoE-Taipei looks forward to deepening outreach connections, especially with other ICoEs in the Asia-Pacific region. Our internationalization strategy includes resources allocated to providing training courses and funding lines designed to stimulate cross-country and cross-disciplinary exchange in countries in the Global South. In 2020, IRDR ICoE-Taipei is planning to organize (or co-organize) three AI international training courses: the *AI on Knowledge-Based-Action for Disaster Risk Reduction (II), AI on Natural Disasters in Nepal, and AI on Hi-ASAP (II).* After these three AIs, a call for Seed Grant proposals will be launched to promote further cooperation between the participants. For networking, a regional meeting or workshop between ICoEs is also planned to be held in 2020. Showcase or panel sessions on the outcomes of activities and grants will be held in three international meetings: the SRI in Brisbane, AOGS in Hongcheon, and AGU in San Francisco.

Future Earth, Taipei

futurearth
research for global sustainability

The 6-year growth of Future Earth, Taipei

Center for Sustainability Science (CSS) actively participates in Future Earth, an international program of sustainability science supported by the International Science Council (ISC). CSS has also supported the operation of "Future Earth, Taipei (FE-Taipei)," a national committee under the umbrella of Future Earth since its launch in 2015 in Academia Sinica (scoped in 2014). Over the past six years, FE-Taipei has grown along with global Future Earth. The missions of FE-Taipei are to organize, co-organize, and participate in Future Earth events and capacity building programs as well as building up domestic networks and linking to international networks. 2019 was a milestone year for FE-Taipei with increases in the number of activities involved and active working groups (WGs) established.

Fig. 1. The CSS assists the operation of Future Earth, Taipei, and actively participates in Future Earth.

Fig. 2. The number of activities in which the CSS is involved regarding Future Earth (2014–2019).

Highlights in 2019

The global Future Earth has established 11 Knowledge-Action Networks (KANs) to *"generate the multifaceted knowledge needed to inform solutions for complex societal issues."* Future Earth Secretariat is actively supporting seven KANs. In 2019, FE-Taipei established seven WGs corresponding to the seven major KANs. Each WG has one convener and one advisor to promote sustainability science locally and connect local research capacity with international science networks. Five of the WGs have successfully invited WG members from academic and stakeholder communities.

With strong linkage to global Future Earth, the Regional Center for Future Earth in Asia, the Health KAN, and the SSCP KAN, FE-Taipei has involved in organizing, co-organizing, and participating in 14 international and eight domestic activities, including conferences, capacity building workshops, discussion meetings, and educational promotion events in 2019. Scientists and stakeholders from 30 countries were involved in those events. For instance, FE-Taipei co-organized the launch event of Health KAN as well as a series of events regarding air pollution and health in Asia. To foster the young generation for building the community of sustainability science in Taiwan, FE-Taipei also carried out two educational activities targeted at the public, undergraduate students, and master's degree students.

In the coming years, FE-Taipei will continue to collaborate with regional and global Future Earth to organize international activities and promote sustainability sciences in Taiwan and Asia and the Pacific. Through WGs, FE-Taipei will expand its connections with other KANs and invite more Taiwan scientists and stakeholders to join the Future Earth networks. Moreover, FE-Taipei plans to organize an annual Assembly to facilitate interactions among scientists and various stakeholder communities in Taiwan involving sustainability research and implementation to further enhance the impacts of sustainability research.

Participating in global Future Earth

The global Future Earth conducted the "Systemic Global Challenges" survey to identify urgent, solution-needed, and systematic global problems. FE-Taipei acted in concordance with Future Earth to inventory the research capacity in Taiwan, conduct surveys among Taiwan networks, integrate results, and send the report to the global Future Earth. The FE-Taipei also nominated several Taiwanese scientists for the Future Earth-Earth Commission, the Steering Committee of Future Earth Health KAN, and the Regional Committee of Future Earth in Asia.

Activities in 2019

1. International Networking

1.1 Activities related to Health KAN - Major Events

1.1.1 Future Earth Health KAN Symposium

FE-Taipei has collaborated with Health KAN and co-organized the Future Earth Health KAN Symposium held on May 20, 2019, in Taipei, Taiwan. This symposium was the official launch event of Future Earth Health KAN. Nearly 40 international and 100 Taiwanese scholars attended. Deputy Minister of the MOST and President of the Academia Sinica gave the opening addresses at this symposium. The introduction of domestic health adaptation researches was also introduced to facilitate interactions between local and international scientists and stakeholders.

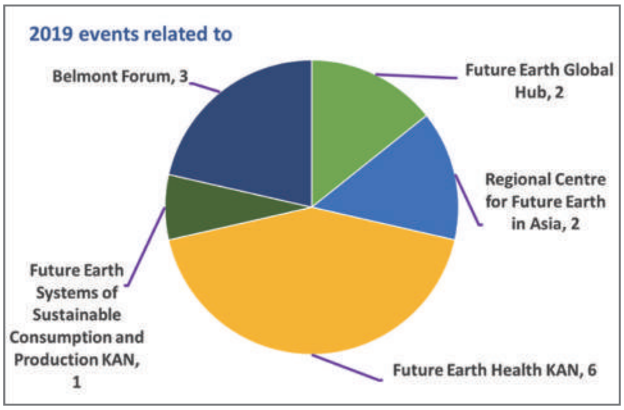


Fig. 3. 2019 Events related to Future Earth and Belmont Forum.

Fig. 4. The 29 countries involved in events (co-)organized by Future Earth, Taipei, in 2019.

Fig. 5. Future Earth Health KAN Symposium and Launch Event held on May 20, 2019.

1.1.2 Closed Meeting of Future Earth Health KAN

FE-Taipei also co-organized the Close Meeting of Future Earth Health KAN held on May 21–23, 2019, right after the Health KAN Symposium. Over 30 key members of Health KAN from 22 countries participated in this meeting to discuss the priority of research topics and the internal governance of Health KAN.

Fig. 6. Close Meeting of Future Earth Health KAN held on May 21–23, 2019.

1.2 Activities related to Health KAN - Workshops and Meetings

1.2.1 Future Earth Workshop for Taiwan Young Scientists – Climate, Health, and Environment

FE-Taipei organized a workshop for Taiwan young scientists to promote sustainability research on climate, health, and environment. The workshop was held on January 9, 2019, in Taipei, Taiwan. Dr. Fumiko Kasuga and Dr. Giles Sioen from Future Earth Japan Global Hub and Health KAN introduced the background and research focus of Health KAN through a video call.

Fig. 7. Future Earth Workshop for Taiwan Young Scientists – Climate, Health, and Environment held on January 9, 2019.

1.2.2 Planning Meeting on Air Pollution Sensing and Health in Asia

The research initiative of the regional collaborative research on air pollution sensing and health in Asia was established under the umbrella of the International Global Atmospheric Chemistry program (IGAC) in 2018. FE-Taipei held its planning meeting on May 17–19, 2019, in Taipei, Taiwan, to discuss the research framework and protocol for "Health Investigation and Air Sensing for Asian Pollution (Hi-ASAP)" among the research teams from 13 countries. Hi-ASAP was later endorsed as a Future Earth Asia regional research activity.

Fig. 8. Planning Meeting on Air Pollution Sensing and Health in Asia held on May 17–19, 2019.

1.2.3 The Session "Regional Collaborative Research on Air Pollution Sensing and Health in Asia"

FE-Taipei organized the session at the 16th Asia Oceania Geosciences Society Annual Meeting (AOGS 2019) held on July 28–August 2, 2019, in Singapore. Six speakers shared their experiences in case studies on the relationship between air pollution exposure and health, including three researchers invited under the Hi-ASAP research framework. This interdisciplinary session generated considerable interest, and FE-Taipei was encouraged to organize similar sessions in future AOGS conferences.

Fig. 9. Session "Regional Collaborative Research on Air Pollution Sensing and Health in Asia" in AOGS 2019 held on July 28–August 2.

1.2.4 Advanced Institute on Health Investigation and Air Sensing for Asian Pollution (AI on Hi-ASAP)

To provide a methodology for research under Hi-ASAP initiative, FE-Taipei co-organized a series of training workshop titled "AI on Hi-ASAP" with the International Science Council, Regional Office for Asia and the Pacific (ISC ROAP) and the Integrated Research on Disaster Risks, International Center of Excellence Taipei (IRDR ICoE-Taipei). The first AI on the Hi-ASAP was held on September 2–6, 2019, in Taipei, Taiwan. A total of 25 scientists studying atmospheric chemistry or public health, from the 11 countries under Hi-ASAP, participated in this workshop and learned how to collect data using the same methodologies within the Hi-ASAP research framework.

1.3 Activities related to SSCP KAN

1.3.1 Academia Sinica Workshop on "Futurability: Intergenerational Equity and Sustainable Governance"

The workshop held on March 22, 2019, was co-organized by FE-Taipei and the Institute of Economics and the Institute of Political Science of Academia Sinica. Four Japanese scholars and four Taiwanese researchers were invited to present novel social research on intergenerational communications. The modeling approach to simulating the thoughts of the "future generation" was introduced.

1.4 Partnership with the Belmont Forum

The Belmont Forum is an alliance of high-level funding agencies around the world and one of the most valuable partners of Future Earth. Future

Fig. 10. Advanced Institute on Health Investigation and Air Sensing for Asian Pollution held on September 2–6, 2019

Fig. 11. Academia Sinica Workshop on "Futurability: Intergenerational Equity and Sustainable Governance" held on March 22, 2019.

Fig. 12. Partnership with the Belmont Forum in AOGS, AGU, and Belmont Forum 10th Anniversary held in 2019.

Earth shares knowledge and scientific ideas to the Belmont Forum to form the co-branded Collaborative Research Actions (CRAs). CRAs are research themes concerning global change through international collaboration. FE-Taipei has actively participated in the Belmont Forum events and assisted the Belmont Forum in promoting the 2019 CRAs in the AOGS, American Geosciences Society (AGU), and Belmont Forum 10th Anniversary events, which was a collaboration between Future Earth and the Belmont Forum Program Office of the Ministry of Science and Technology (MOST), Taiwan.

1.5 Other International Events

1.5.1 TERRA School 2019

The Transdisciplinarity for Early caReer Researchers in Asia (TERRA) School is a short-term, intensive course on co-creation and transdisciplinary research practices, organized by the Research Institute for Humanity and Nature in collaboration with the Regional Centre for Future Earth in Asia. Future Earth nominated two young scientists, Dr. Chia-Ying Jessie Ko and Dr. Wan-Chen Lee from the National Taiwan University, as trainees. Both nominees successfully participated in the TERRA School 2019, where they acquired knowledge on the theories and practical aspects of transdisciplinarity (TD) by using case studies, project-based site visits, and hands-on experiences designing a TD proposal. The proposal was designed through group discussions and activities with researchers from diverse backgrounds.

1.5.2 Regional Scientific Meetings

The Executive Secretary, Dr. Shih-Chun Candice Lung, participated in the International Global Atmospheric Chemistry–Monsoon Asian and Oceania Networking Group (IGAC-MANGO) meeting, science workshop, and training course held on November 28–30, 2019, in Nainital, India. Dr. Lung also participated in the Science Council of Asia (SCA) 2019 conference held on December 3–5, 2019, in Nay Pyi Taw, Myanmar. In addition, the Science Officer, Dr. Chia-Hsing Jeffery Lee, was invited to chair the session namely "Soil Management and Climate Change" in the 14th International Conference of the East and Southeast Asia Federation of Soil Science Societies (ESAFS) held on November 3–8, 2019, in Taipei, Taiwan.

Fig. 13. 2019 TERRA School held on December 9–13, 2019.

Fig. 14. CSS actively participated in regional scientific events related to sustainability in 2019.

1.5.3 The 3rd International Conference on Integrated and Innovative Solutions for Circular Economy

CSS also actively participates in sustainability-related events organized by the public and private sectors in Taiwan. The 3rd International Conference on Integrated and Innovative Solution for Circular Economy organized by CTCI Education Foundation comprised four principal themes: (1) Governance and Road Maps, (2) Sustainable Finances, (3) Sustainable Processes, and (4) Business Models.

2. Domestic Promotion

2.1 FE-Taipei WGs

FE-Taipei established seven WGs corresponding to the Future Earth KANs, namely (1) Emergent Risks and Extreme Events (Risk), (2) Health, (3) Ocean, (4) Natural Assets, (5) Systems of Sustainable Consumption and Production (SSCP), (6) Urban, and (7) Water–Energy–Food (WEF) Nexus. FE-Taipei invited coordinators and advisors of each WG to attend the Kickoff Meeting held on April 30, 2019, in Academia Sinica (Fig 15). The discussion was focused on how to carry out tasks to promote thematic sustainability sciences in Taiwan, extend local networks, and encourage participation in corresponding Future Earth KAN. (Table 1.)

Fig. 15. Kickoff Meeting for the Future Earth, Taipei, WGs held on April 30, 2019.

2.2 Educational Promotion

2.2.1 Promotion in the University

During September - December 2019, a joint college course, "Sustainable Future and Ecology," invited FE-Taipei to introduce Future Earth. The Executive Secretary, Dr. SC Candice Lung, and Science Officer, Dr. CH Jeffery Lee, of FE-Taipei gave lectures on Future Earth, systems thinking, and sustainability science development in Taiwan. Master's students from National Taiwan University, National Tsing Hua University, National Dong Hwa University, National Chung Hsing University, and Tunghai University attended the lecture. Dr. Lee also participated in the field trip and shared his experiences in ecological investigations.

Fig. 16. The CSS promoted Future Earth in the University lecture "Sustainable Future and Ecology" in 2019.

2.2.2 Open House of Academia Sinica

In the 2019 annual Academia Sinica open-house event, FE-Taipei presented its achievements. The topics of "What is sustainability," "Why sustainability matters," and sustainable development goals were introduced to the public. One hands-on activity was also organized with air pollution sensors to engage participants with low-cost sensors for aerosols.

Fig. 17. The booth of CSS in Open House of Academia Sinica on October 26, 2019.

2.3 FE-Taipei Regular Meetings

The FE-Taipei committee members discuss strategies and activity plans in regular meetings to promote sustainability science in Taiwan. In 2019, the plenary meeting of the 2nd FE-Taipei committee was held on January 30 and the standing committee meetings on January 30 and November 8. The 3rd FE-Taipei committee was established at the end of this year consists of 25 natural, societal, and economic scientists and 4 representatives from industry and government organizations and units. (Table 2.)

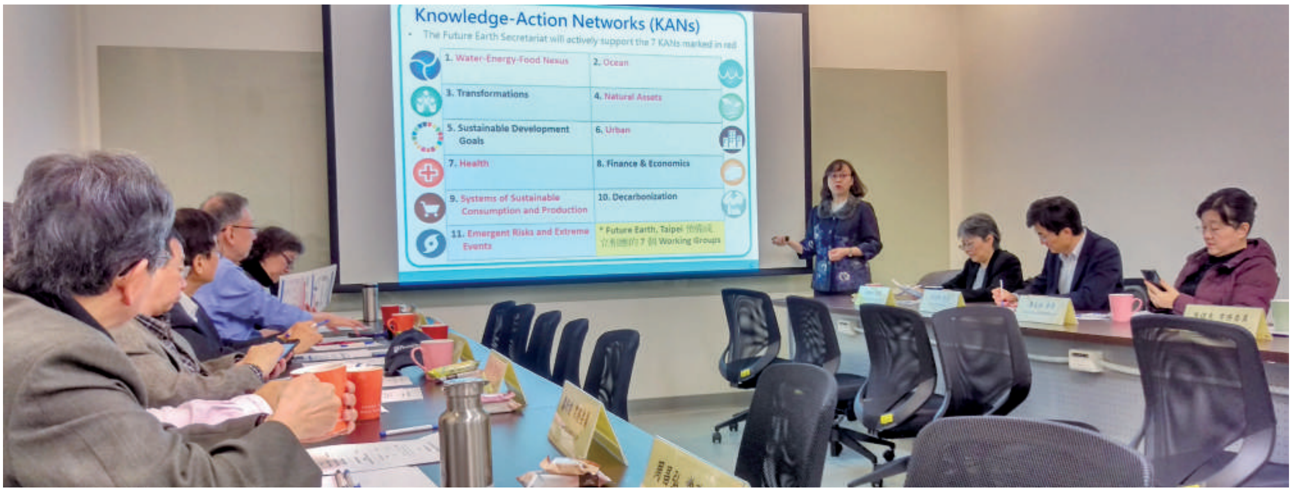


Fig. 18. Future Earth, Taipei National Committee meeting held on January 30, 2019.

2.4 Other Events on Sustainability Sciences

2.4.1 Discussion Meeting regarding the Collaboration between FE-Taipei and the MOST Belmont Forum Platform

The MOST also has the responsibility to promote sustainability science and participate in the Belmont Forum. The Belmont Forum is the principal funding source of the research themes that Future Earth promotes. To create a synergy of research capacity and resources, approximately 15 scientists, experts, and officers from FE-Taipei and the MOST attended a meeting held on January 14, 2019, in Taipei and discussed strategies for the future collaboration.

Table 1. The leadership of the Future Earth, Taipei WGs established in 2019

Working Group	Coordinator	Advisor
Risk	Jian-Hong Wu	Yue-Gau Chen
Health	Shih-Chun Candice Lung	Huey-Jen Jenny Su
Ocean	Tung-Yuan Ho	Chen-Tung Arthur Chen
Natural Assets	Yu-Chung Chiang	Chang-Hung Chou
SSCP	Daigee Shaw	Eugene Chien
Urban	Shu-Li Huang	Hsin-Huang Michael Hsiao
WEF Nexus	Yu-Ping Lin	Chao-Han Liu

Table 2. List of The 3rd National Committee of Future Earth, Taipei [November 2019-November 2021]

Ching-Cheng Chang	Yue-Gau Chen	Chen-Tung Arthur Chen
Yu-Chung Chiang	Eugene Chien	Chang-Hung Chou
Tyng-Ruey Chuang	Hsin-Huang Michael Hsiao	Ping-Hui Hsieh
Shu-Li Huang	Fei-yu Kuo	Ling-Ling Lee
Ming-Hsu Li	Tze-Luen Lin	Hsing-juh Lin
Jiun-Chuan Lin	Neng-Hui Lin	Yu-Pin Lin
Minn-Tsong Lin	Chao-Han Liu*	Ching-Hua Lo
Shih-Chun Candice Lung§	Wen-Harn Pan	Daigee Shaw
Huey-Jen Jenny Su	Huei-min Tsai	Jough-Tai Wang
Pao-Kuan Wang	Shin-Cheng Yeh	

*: Chair; §: Executive Secretary

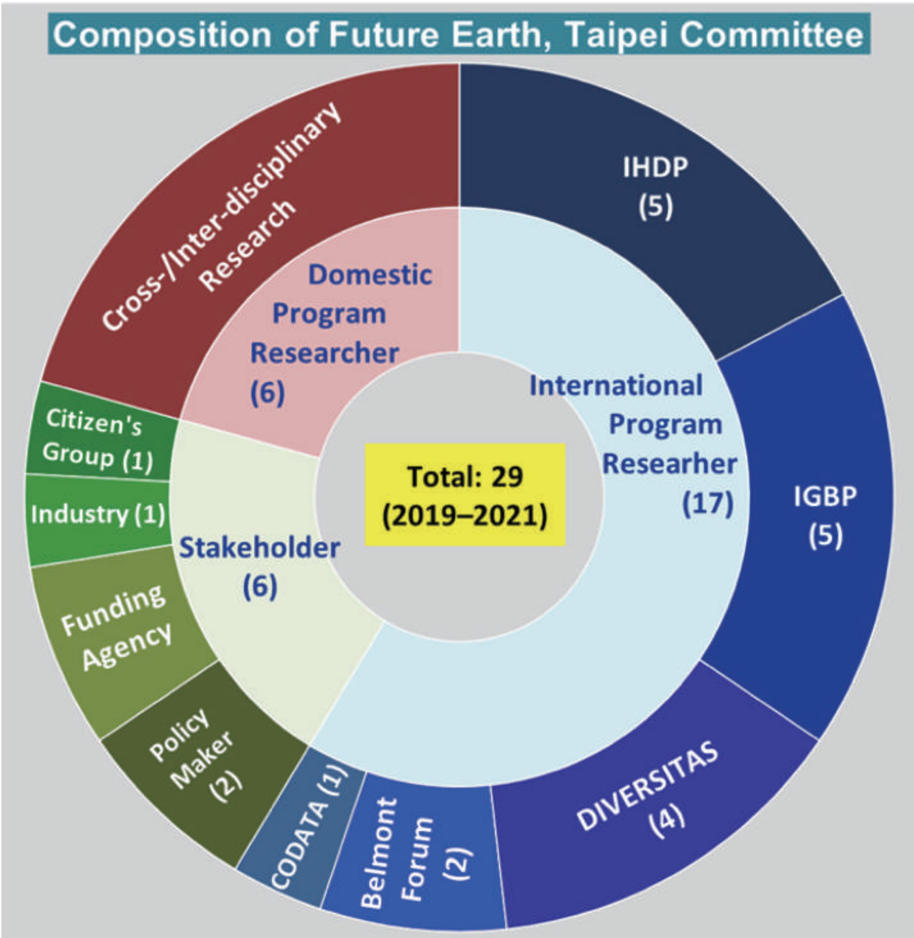


Fig. 19. The composition of the 3rd National Committee of Future Earth, Taipei.

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