

AQUATIC INVASIVE ALIEN SPECIES IN SOUTHEAST ASIA

National University of Singapore | 26 & 27 July 2017



**Pusat Khidmat Maklumat Akademik
UNIVERSITI MALAYSIA SARAWAK**

P. KHIDMAT MAKLUMAT AKADEMIK
UNIMAS



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WELCOME

On behalf of the organising committee, welcome and thank you for joining us for the (Aquatic Invasive Alien Species in Southeast Asia (AIASSEA) Symposium 2017,) organised by the Department of Biological Sciences (DBS) and the Lee Kong Chian Natural History Museum (LKCNHM) of the National University of Singapore (NUS).

Invasive alien species (IAS) are becoming more prevalent in Southeast Asia, resulting in an expanding body of IAS research pertinent to this highly biodiverse region and to the tropics. The overall goal of this symposium is to disseminate and share current knowledge and ongoing research on aquatic IAS in Southeast Asia and beyond. This emphasis on fundamental as well as applied research conducted on IAS in the region complements other regional meetings, which tend to feature country statuses, management strategies, and inter-governmental networking.

These two days of talks will mostly focus on aquatic IAS—with a representation of regional and local work, from freshwater to marine habitats, and ranging from faunistic and research overviews to species-specific biological studies. In addition, presentations on ecological mechanisms in biological invasions, and, in particular, four highly topical plenary talks that kick off the symposium proper or certain thematic sessions, provide a broader invasion biology perspective. David Dudgeon will explore the very basis of the threat posed by IAS on Asia's threatened freshwater biodiversity. Hugh MacIsaac will highlight various methods and technologies for detecting aquatic IAS. Fred Wells will reveal the scale and issues of invasive marine species in Southeast Asia. Jaimie Dick will introduce an important new tool for predicting invasive species impacts, one of the cornerstones of IAS management.

This is, as far as we know, among the first IAS research meetings in Southeast Asia, and we are honoured and grateful to all our invited researchers for agreeing to participate in this event. We acknowledge the generous sponsorship of the Lee Foundation; and the Faculty of Science (FoS), DBS, and LKCNHM (all NUS). And finally, on a personal note, I am indebted to the rest of the organising committee, including co-organising chair, Dr Tan Heok Hui (LKCNHM), Freshwater and Invasion Biology Lab members, Rayson Lim, Zeng Yiwen, Liew Jia Huan, Kenny Chua, Jeffrey Kwik, and Low Bi Wei for the enthusiasm and great work; and various FoS, DBS and LKCNHM colleagues and students for their time and professional support in bringing this symposium to fruition.

Darren C. J. YEO

Chair

Organising Committee

AIASSEA Symposium 2017

ORGANISERS AND SPONSORS

Jointly organised and co-sponsored by:



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Faculty of Science



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Natural History Museum

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Darren C. J. YEO

Department of Biological Sciences (DBS),
National University of Singapore (NUS)

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AQUATIC INVASIVE ALIEN SPECIES IN SOUTHEAST ASIA

National University of Singapore (NUS), Singapore
26 & 27 July 2017

Introduction of invasive alien species (IAS) resulting from anthropogenic removal or bypassing of natural dispersal barriers is a global issue with far-reaching environmental, economic, and human health impacts. In aquatic environments, the frequency and extent of IAS introduction and establishment can often be exacerbated by the intensification of socio-economic activities, particularly introduction pathways that are associated with international trade.

For the biodiverse Southeast Asian region, the impacts of aquatic IAS could worsen in the coming decades with increasing urbanisation and resource exploitation. From an ecological perspective, IAS can impact native communities directly (e.g., predation and competition) and indirectly (e.g., habitat modification, alteration of food web and trophic interactions). Economic impacts of IAS include threats to food security as well as control/management costs and opportunity costs. Human health impacts can be in the form of physical injury or zoonotic diseases.

A general dearth of knowledge of IAS in Southeast Asia, however, has been highlighted. And while there have been some localised studies, substantial gaps (including knowledge of ongoing research) remain that will likely confound efforts to understand, prevent, and manage the introduction, spread, and impacts of IAS particularly at the regional level. The knowledge gap will also likely hamper Southeast Asian countries' progress towards identification, prioritisation, and control/management of IAS and pathways—a key 2020 Aichi Biodiversity Target (Target 9 under Strategic Goal B) of the Convention on Biological Diversity's Strategic Plan for Biodiversity (<https://www.cbd.int/sp/targets/default.shtml#GoalB>).

The AIASSEA 2017 symposium aims to bring together leading international and regional researchers with the overall goal of disseminating and sharing current knowledge, ongoing research, and expertise on aquatic invasive alien species in Southeast Asia.

PROFILES OF PLENARY SPEAKERS



Jaimie T. A. DICK

Queen's University Belfast, United Kingdom

Jaimie Dick is Professor of Invasion Ecology at Queen's University Belfast, and Director of the Queen's Marine Laboratory, Portaferry. Jaimie was Director of the Quercus Biodiversity and Conservation Centre. Jaimie uses classical ecological concepts and techniques to elucidate mechanisms of ecological impact of invasive species across taxonomic and trophic groups.



David DUDGEON

The University of Hong Kong, Hong Kong SAR, China

David Dudgeon is Chair Professor of Ecology & Biodiversity and Director of the School of Biological Sciences at the University of Hong Kong. There, he researches and writes about the streams and rivers of monsoonal East Asia, and the animals that live in and around them. Dudgeon is Editor-in-Chief of *Freshwater Biology*.



Hugh MACISAAC

University of Windsor, Canada

Hugh MacIsaac is a senior Canada Research Chair in Aquatic Invasive Species at the University of Windsor. He was Director of the Canadian Aquatic Invasive Species networks, which conducted invasive research in freshwater and marine ecosystems across Canada. Hugh is interested in vectors that transmit invasive species, and the issues of false positives and false negatives in invasive species research.



Fred WELLS

Murdoch University, Australia

Fred Wells is an Adjunct Professor at Murdoch University in Perth. He was the President of *Unitas Malacologica* and Senior Curator (Malacology) at the Western Australian Museum where he has examined distributional patterns of molluscs in the western third of the continent and placed this in a broader geographical context. Much of the work involved documentation of molluscan assemblages in areas not previously investigated by scientists, not only in Western Australia, but also in biogeographically related areas. His research has included all major habitat types in Western Australia, with a particular focus on coral reefs and mangroves.

PROGRAMME: DAY ONE

26 July 2017

REGISTRATION 8:15–8:50 am

OPENING REMARKS 8.50–9.00 am

YU Hao

Head, Department of Biological Sciences, National University of Singapore

Peter K. L. NG

Head, Lee Kong Chian Natural History Museum, National University of Singapore

Darren C. J. YEO

Organising Chair, AIASSEA Symposium, Department of Biological Sciences, National University of Singapore

Plenary Talk 1 9.00–9.45 am

Freshwater Biodiversity under Global Threat: What are the Risks from Invasive Species in Asia?

David DUDGEON, *The University of Hong Kong, Hong Kong SAR, China*

Plenary Talk 2 9.45–10.30 am

False Negatives and False Positives Hinder Early Detection and Rapid Response for Aquatic Alien Invasive Species

Hugh MACISAAC, *University of Windsor, Canada*

TEA BREAK 10.30–11.00 am

SESSION: OVERVIEW OF BIOLOGICAL INVASIONS

Invited Talk 1 11.00–11.15 am

Threat of Invasive Alien Species in Southeast Asia Looms Larger

Malcolm SOH, *University of Western Australia, Australia*

Invited Talk 2 11.15–11.30 am

Overview of Introduced Freshwater Mollusc Research in Singapore

NG Ting Hui, *Chulalongkorn University, Thailand*

Invited Talk 3 11.30–11.45 am

Aquatic Alien Invasive Fish Species in Indonesia

Renny Kurnia HADIATY, *Indonesian Institute of Sciences (LIPI), Indonesia*

Invited Talk 4 11.45am–12.00 pm

Alien Freshwater Fish Cultured in Malaysia: Economic Development or Native Fish Species Extinctions

KHAIRUL ADHA A. Rahim, *Universiti Malaysia Sarawak, Malaysia*

Invited Talk 5 12.00–12.15 pm

Non-native Freshwater Fishes of Singapore—An Update
TAN Heok Hui, *National University of Singapore, Singapore*

Invited Talk 6 12.15–12.30 pm

Aquatic Alien Invasive Species in Northern Thailand
Apinun SUVARNARAKSHA, *Maejo University, Thailand*

LUNCH 12.30–1.45 pm

SESSION: MARINE INVASIONS IN SOUTHEAST ASIA

Plenary Talk 3 1.45–2.30 pm

Invasive Marine Species: A Hidden Problem in Southeast Asia
Fred WELLS, *Murdoch University, Australia*

Invited Talk 7 2.30–2.45 pm

Current Status of Marine Non-Indigenous Species in the Western Pacific Region and a Case Study of the Introduced Pacific White Shrimp *Litopenaeus vannamei* in Thailand
Suchana Apple CHAVANICH, *Chulalongkorn University, Thailand*

Invited Talk 8 2.45–3.00 pm

Non-Indigenous Marine Species in Singapore: An Update
Zeehan JAAFAR, *National University of Singapore, Singapore*

Invited Talk 9 3.00–3.15 pm

Do Singapore's Seawalls Host Non-Native Marine Molluscs?
TAN Wen Ting, *National University of Singapore, Singapore*

Invited Talk 10 3.15–3.30 pm

New Record of an Invasive Marine Mussel *Mytella strigata* (Bivalvia: Mytilidae) in Singapore
TAN Koh Siang, *National University of Singapore, Singapore*

Invited Talk 11 3.30–3.45 pm

Geographic Spread of an Alien Aquaculture Species, *Penaeus vannamei* and their Ecological Impacts in Eastern Thailand
Wansuk SENANAN, *Burapha University, Thailand*

TEA BREAK 3.45–4.15 pm

SESSION: BIOLOGY OF INVASIVE SPECIES (I)

Invited Talk 12 4.15–4.30 pm

The Current Status and Management of the Golden Apple Snail in Vietnam
DO Van Tu, *Institute of Ecology and Biological Resources, Vietnam*

Invited Talk 13 4.30–4.45 pm

The ‘Unseen’ Invader has Settled Down: Observations on *Arctodiaptomus dorsalis* in Philippine Lakes

Rey Donne S. PAPA, *University of Santo Tomas, Philippines*

Invited Talk 14 4.45–5.00 pm

Introduced Decapod Crustaceans in Indonesia’s Inland Waters

Daisy WOWOR, *Indonesian Institute of Sciences (LIPI), Indonesia*

Invited Talk 15 5.00–5.15 pm

Invasive Apple Snails, *Pomacea* spp. as Pest in Irrigated Rice: Present Status, Impact and Management

Ravindra Chandra JOSHI, *Pampanga State Agricultural University, Philippines*

END OF DAY ONE

PROGRAMME: DAY TWO

27 July 2017

REGISTRATION 8.30–9.00 am

SESSION: ECOLOGICAL MECHANISMS IN BIOLOGICAL INVASIONS

Plenary Talk 4 9.00–9.45 am

Predicting Invasive Species Impacts under Context-Dependencies

Jaimie T. A. DICK, *Queen's University Belfast, United Kingdom*

Invited Talk 16 9.45–10.00 am

Potential Effects of Climate Change in Cognitive Abilities in an Invasive Fish

Kit MAGELLAN, *The University of Hong Kong, Hong Kong SAR, China*

Invited Talk 17 10.00–10.15 am

Investigating the Ecology of Invasive Alien Species in Singapore's Fresh Waters

Darren C. J. YEO, *National University of Singapore, Singapore*

Invited Talk 18 10.15–10.30 am

Impacts of Introgression on Natural Communities

Keren SADANANDAN, *National University of Singapore, Singapore*

Invited Talk 19 10.30–10.45 am

Bioeconomic Modeling to Support Risk Analysis for Invasive Species

L. Roman CARRASCO, *National University of Singapore, Singapore*

TEA BREAK 10.45–11.15 am

SESSION: BIOLOGY OF INVASIVE SPECIES (II)

Invited Talk 20 11.15–11.30 am

Exotic Aquatic Macrophytes in Tropical Lakes: Management and Potential Applications

Darren Zong Han SIM, *National University of Singapore, Singapore*

Invited Talk 21 11.30–11.45 am

Measuring the Effects of Temperature and Food Concentration on *Arctodiaptomus dorsalis*: The Importance of Laboratory Culture Studies in Invasive Copepod Research

Dino T. TORDESILLAS, *University of Santo Tomas, Philippines*

Invited Talk 22 11.45 am–12.00 pm

Current Knowledge of an Invasive Alien Species, *Gambusia affinis*, in Kenyir Reservoir

Amirrudin AHMAD, *Universiti Malaysia Terengganu, Malaysia*

Invited Talk 23 12.00–12.15 pm

Movement of Frogs and Turtles Relevant to Bioinvasions on Borneo
Indraneil DAS, *Universiti Malaysia Sarawak, Malaysia*

Invited Talk 24 12.15–12.30 pm

The Singapore Crayfish Story: Understanding the Drivers and Impacts of the *Cherax quadricarinatus* invasion
ZENG Yiwen, *National University of Singapore, Singapore*

CLOSING REMARKS 12.30–12.45 pm

Darren C. J. YEO

*Organising Chair, ALASSEA Symposium, Department of Biological Sciences,
National University of Singapore*

LUNCH 12.45–2.00 pm

END OF SYMPOSIUM

ABSTRACTS

Plenary Talk 1

Freshwater Biodiversity under Global Threat: What are the Risks from Invasive Species in Asia?

David DUDGEON

School of Biological Sciences, The University of Hong Kong, Hong Kong SAR, China

Human impacts on the biosphere are sustained and now so pervasive that the planet has entered a new geological epoch—the Anthropocene—in which many Earth-system processes are strongly influenced by humans. Globally, fresh waters exhibit conspicuous Anthropocene signatures, and are hotspots for endangered biodiversity. They host almost 10% of animal species, including one third of vertebrates, but encompass less than 1% of the Earth's surface. Trajectories of human population growth, water use and the consequential disturbance and degradation of inland waters have risen steeply during the Anthropocene, accompanied by impoverishment of the freshwater fauna. These animals are far more imperiled than their terrestrial or marine counterparts, with populations trending downward at twice the rate of species on land. Freshwater ecosystems in densely-populated Asia have been profoundly altered, and the extinction of the Yangtze River dolphin is emblematic of on-going regional losses of freshwater animals.

The Anthropocene world could, however, merit an alternative title: the Homogenocene. Humans have facilitated the movement of plants and animals, thereby homogenising the global biota as species are established far beyond their natural ranges. Some are highly invasive with profound impacts on native biodiversity in receiving freshwater ecosystems. As we face a no-analogue future, what is the magnitude of threats posed by invasive species in freshwater ecosystems already at risk from multiple interacting stressors? Do, in fact, invasives pose an existential threat to freshwater biodiversity in Anthropocene Asia? And, have we sufficient high-quality evidence to assign unambiguous blame on invasives for declines of native species? I will present examples from Hong Kong—where the human-dominated landscape has been subject to multiple invasions—in an attempt to answer these questions and, perhaps, indicate a way forward.

Plenary Talk 2

False Negatives and False Positives Hinder Early Detection and Rapid Response for Aquatic Alien Invasive Species

Hugh MACISAAC

Great Lakes Institute for Environmental Research, University of Windsor, Canada

Detecting Aquatic Alien Invasive Species (AAIS) early is a high management priority for most countries, yet in practice is very challenging given the underwater nature of the target and its low abundance and geographic limitation. These problems may result in false negative assessments. Molecular methods and advanced particle counters (e.g., FlowCAM) offer opportunities to detect some AAIS even when present at very low abundances, thereby lowering false negatives. In the case of molecular methods, detection can be improved dramatically (i.e., orders of magnitude) versus standard microscopy. However, molecular methods are prone to inflated false positives if primers used in PCR are not species-specific, or if sequencing or other errors occur when using metabarcoding of heterogeneous field samples. FlowCAM technology uses image analysis to assign species identities in mixed species samples. This technology has been used successfully to identify algae but heretofore was not used for larger organisms owing to size restrictions associated with the equipment. FlowCAM can allow rapid analysis of samples and is better able to identify some rare species, though morphologically-similar species are better identified by classical microscopy methods. My presentation will highlight current opportunities and limitations of different methods of analysis.

Plenary Talk 3

Invasive Marine Species: A Hidden Problem in Southeast Asia

Fred WELLS

Murdoch University, Australia

Invasive marine species (IMS) are widely regarded as being one of the major anthropogenic threats to the global marine environment. Fortunately, few introduced marine species become invasive, but those that do can alter the structure of local ecosystems, threaten commercial fisheries and aquaculture, introduce diseases into other marine species and even humans and foul industrial structures and piping. Southeast Asia is the heart of the megadiverse coral triangle, with thousands of shallow water marine species. Unfortunately, the taxonomy and distributions of many marine species in Southeast Asia are not well documented, so the scale of the IMS problem is not known. The region both exports IMS species to other parts of the world and is a recipient of IMS from other areas. There is also translocation of IMS species within the region, providing a complex, but essentially hidden problem. The tropical waters provide a relatively homogenous environment with few barriers to the translocation of IMS. The extensive economic interactions within the region provide several major mechanisms for the spread of IMS, including biofouling on vessels, in ballast water, as live food, etc. Tropical species on the Australian national IMS target list plus a literature search can be used to develop a provisional Southeast Asian IMS list. An integrated program of prevention of IMS arrivals, monitoring to detect species that penetrate the quarantine barriers and responses to infections can be used to minimise the impacts of IMS. Prevention is the key as removal of marine species is almost impossible once they become established in an area.

Plenary Talk 4

Predicting Invasive Species Impacts under Context-Dependencies

Jaimie T. A. DICK

School of Biological Sciences, Queen's University Belfast, United Kingdom

Invasive species impacts are notoriously unpredictable and highly context-dependent, making invader ecological impact prediction difficult. My new metric of invader impact, "Relative Impact Potential" (RIP), blends the classic Functional Response (FR; consumer *per capita* effect) and Numerical Response (NR; consumer population response) with the "Parker-Lonsdale equation" (Impact = Range × Abundance × Effect), to give $RIP = FR \times Abundance$. The RIP metric is an invader/native ratio, values > 1 predicting that invader ecological impact will occur, and increasing values above 1 indicating increasing ecological impact. Across a diverse range of trophic and taxonomic groups, including predators, herbivores, animals and plants (22 invader/native systems, 47 individual comparisons), high impact invaders were significantly associated with higher FRs compared to native trophic analogues. However, the RIP metric substantially improves this association, with 100% predictive power of high impact invaders. Further, RIP scores were significantly and positively correlated with two independent ecological impact scores for invaders, allowing prediction of the degree of impact of invasive species with the RIP metric. Since both *per capita* effects and abundances of invaders can be measured across abiotic and biotic contexts, the RIP metric could substantially improve invader impact prediction. For example, FRs are sensitive to temperature, oxygen, salinity, parasitic infection and multiple predator effects (MPEs). RIP thus provides an explanatory and predictive tool for scientists, managers, practitioners and legislators in a changing world with increasing invasion threats. In particular, the RIP metric, for the first time, could predict the likely ecological impacts of potential new invasive species lacking prior invasion history.

Invited Talk 1

Threat of Invasive Alien Species in Southeast Asia looms larger

Malcolm SOH

School of Animal Biology, University of Western Australia, Australia

Southeast Asia (SEA) is particularly vulnerable to threats of invasive alien species (IAS) as it has a high number of endemics due its largely insular nature. We aimed to reassess the extent of IAS impacts since an earlier review in 2009 using the Global Invasive Species Database managed by the International Union for Conservation of Nature. We also explored the plausibility of socioeconomic causes behind any increases in IAS and suggest priorities for their control in the region. From 2009 to 2016, the number of IAS in SEA increased by 162% on average and ranged from 105% in Singapore to 341% in Myanmar. Although SEA had the fewest number of IAS compared to other geographic regions, it had the second highest concentration of IAS per area after Oceania. Plants had the highest representation of IAS in SEA, followed by fishes and insects. Population size in 2015 in each of the Southeast Asian countries was highly correlated to the number of IAS in 2016. From 2008 to 2015, the change in the volume of imports was also correlated to the change in IAS for each country in SEA. Our recommendations include drafting a priority list of IAS in SEA to unify efforts to tackle invasives that pose the greatest threat, increased monitoring to prevent further IAS introductions and naturalized aliens from becoming invasive and raising public awareness on the detrimental impacts of IAS.

Invited Talk 2

Overview of Introduced Freshwater Mollusc Research in Singapore

NG Ting Hui^{1*}, TAN Siong Kiat², TAN Heok Hui² & Darren C. J. YEO³

¹*Department of Biology, Chulalongkorn University, Thailand*

²*Lee Kong Chian Natural History Museum, National University of Singapore, Singapore*

³*Department of Biological Sciences, National University of Singapore, Singapore*

*Presenting contributor

Freshwater molluscs in Singapore are almost exclusively found in urban habitats, and at least two thirds are probably introduced species. This talk highlights the outcomes of recent research on introduced freshwater molluscs in Singapore, and will focus on two areas: 1) ornamental pet trade as an introduction pathway; and 2) status of introduced gastropods in Singapore. 1) A morphological and molecular study of freshwater mollusc diversity in the ornamental pet trade, including non-ornamental species, i.e., hitchhikers on plants, or sold as fish feed, recorded fifty-nine species (mostly from the Oriental region), which accounts for almost half of known introduced freshwater molluscs in Singapore. A quarter of the ornamental trade species have a history of introduction, including the globally-invasive apple snails *Pomacea* spp. (Ampullariidae). 2) At least 33 freshwater mollusc species have been introduced in Southeast Asia, including globally-invasive and cryptogenic species (of unknown origin), with Singapore having the highest number (23 species). The high proportion of introduced species may reflect the status of other similar urban centres in Southeast Asia that are rapidly globalising. More specifically, recent research in Singapore on freshwater snails (Gastropoda) reported two new records of introduced species as well as clarified the confused taxonomy or cryptogenic status of four long-established introduced species. Clarifying the statuses of poorly-known freshwater gastropods in the region can help to prioritise conservation and management efforts of native and invasive species, respectively.

Invited Talk 3

Aquatic Alien Invasive Fish Species in Indonesia

Renny Kurnia HADIATY

Museum Zoologicum Bogoriense (MZB), Indonesian Institutes of Sciences (LIPI), Indonesia

Indonesia is an archipelago with the fourth largest population in the world (263.5 million people). In terms of combined sea and land area, Indonesia is the 7th largest country and it also has the 14th largest land area in the world. As the country with the largest number of islands in the world, Indonesia consists of 17,504 islands. From the westernmost island Sabang to the easternmost Merauke, there are 423 rivers, 139 lakes and 495 dams.

Indonesia is unquestionably one of the world's most biodiverse countries, with 25% of global fish diversity. The Indonesian government established laws to protect biodiversity (including fishes) since 1992, and the laws are updated when the need arises.

As of 1993, about 17 fish species had been deliberately introduced into Indonesian fresh waters with *Carassius auratus* and *Cyprinus carpio* among the first introduced species. The introductions were for the ornamental trade and aquaculture. About 20 years later, the number of introduced species has increased four-fold. In 2009, the Ministry of Marine and Fisheries launched the prohibition of 30 invasive fish species from five families into Indonesian waters. The regulation was updated in 2014 and was expanded to include 87 fish species from 28 families. Some invasive fish species are known to impact native species, i.e., the flowerhorn cichlid preyed on endemic gobiids (*Glossogobius matanensis*) in Lake Matano, the alligator gar were documented attacking human teenagers in Jatiluhur dam, while in Sumatra, *Arapaima* fishes were observed when there was a drop in water levels.

Invited Talk 4

Alien Freshwater Fish Cultured in Malaysia: Economic Development or Native Fish Species Extinctions

KHAIRUL ADHA A. Rahim

Department of Aquatic Science, Universiti Malaysia Sarawak, Malaysia

Human activities to increase economic productivity and food supplies have contributed to the introduction of alien fish into freshwater ecosystems. The introduction of alien fishes for aquaculture, recreational fisheries, stocking enhancement, biological control and aquarium fish industry has also led to the establishment of alien species in local aquatic habitats. More than 24 species of alien fishes, mainly for culture have been introduced into Malaysian freshwaters for the past 40 years. It is likely that alien species in Malaysia have positive impacts on various economies in the country. Despite some arguably positive effects on biodiversity at the local scale, an overwhelming amount of evidence indicates the profoundly negative effects of alien species introduction on genetic diversity as a whole. Presently, there are neither documented information nor specific research programs in Malaysia about the roles and contributions of alien fish on aquaculture development as well as the impacts on other native fish fauna. Therefore, the documentation of the influence and the effects of alien fish species on aquaculture development in Malaysia is vital. If alien species abundance increases in the future, it will be easier to identify changes, particularly on native fish fauna and other natural resource related to the increased abundance of alien fish or other causes.

Invited Talk 5

Non-native Freshwater Fishes of Singapore—An Update

TAN Heok Hui

Lee Kong Chian Natural History Museum, National University of Singapore, Singapore

An overview of all available published literature on freshwater fishes of Singapore, including fisheries reports, is presented. A total of 118 species (including seven hybrids) are presently known from Singapore (1849 to present), of which about 40 species have established breeding populations in mainly artificial habitats. Currently 43 native fish species are still extant in the waterways of Singapore; thus 74.4 % of freshwater fish taxa in Singapore are non-native in origin. The more recent records have been mainly from e-journals and efforts of citizen science.

Invited Talk 6

Aquatic Alien Invasive Species in Northern Thailand

Apinun SUVARNARAKSHA

Faculty of Fisheries Technology and Aquatic Resources, Maejo University, Thailand

Alien aquatic species in Thailand are divided into two groups, (i.e., alien aquatic plants e.g., water hyacinth (*Eichhornia crassipes*) and alien aquatic animals (e.g., red craw shrimp, Chinese carps, Indian carps, suckers, *Oreochromis niloticus*, and *O. mossambicus*). Some species have economic values (e.g., *Oreochromis niloticus* and *Cyprinus carpio*) while others do not, and are considered to be invasive (e.g., *Pomacea canaliculata*). The damage caused by invasive alien species is not a desirable outcome but some cultivated alien species have gained economic importance. In first order streams, prominent invaders include *Gambusia affinis*, which was introduced as a biological control of mosquito larvae, but they also feed on native invertebrate larvae. Other invaders include *Clarias gariepinus* and *Clarias* hybrids, which are escapees from farms or constitute ceremonial releases during important Thai traditional festivals. Lowland invasive species include *Clarias gariepinus*, *Clarias* hybrid, *Cyprinus carpio*, *Labeo rohita*, *Cirrhinus cirrhosus*, and *Pterygoplichthys disjunctivus*, *Oreochromis niloticus*, *O. mossambicus*, *Clarias gariepinus*, *Piaractus brachypomus*, Chinese carps and Indian carps were introduced as protein sources, while *Arapaima gigas*, *Cichla ocellaris*, and *Tilapia buttikoferi* were introduced as ornamental or game fish which were subsequently introduced into natural water bodies. Conversely, *Channa micropeltes*, a species native to Thailand was first introduced as a game fish in reservoirs but has since been classified invasive because it feeds on small, commercially important cyprinids. The overall management strategies adopted in dealing with invasive fish species range from "no action" and "single-component control tactics" to "integrated invasive alien fish control".

Invited Talk 7

Current Status of Marine Non-Indigenous Species in the Western Pacific Region and a Case Study of the Introduced Pacific White Shrimp *Litopenaeus vannamei* in Thailand

Suchana Apple CHAVANICH

Department of Marine Science, Chulalongkorn University, Thailand

Recently, UNESCO/IOC Sub-Commission for the Western Pacific (WESTPAC) project on the “Coastal Marine Biodiversity and Conservation” had organized three regional workshops related to marine non-indigenous species (NIS), and published a report on current status of marine NIS in the Western Pacific region. This report aimed to consolidate the available information on the current status and list of marine NIS in nine countries; China, Indonesia, Japan, Republic of Korea, Malaysia, Philippines, Singapore, Thailand, and Vietnam. The report also attempted to provide a general review of on-going research and management in each country. Pathways of the introduction of marine NIS were investigated and lists of marine NIS in each country in the WESTPAC were compiled. The information from this report can serve as baseline data for further research on marine NIS in the region. In addition, an example of a case study of the introduced Pacific white shrimp, *Litopenaeus vannamei* (Boone, 1931), in Thailand will be presented. Studies were conducted to investigate the impact and threats of escape cultured white shrimp on native shrimps and crabs in marine ecosystems. The results showed that *L. vannamei* may pose a serious threat to native shrimp species if it fully establishes in marine waters of Thailand.

Invited Talk 8

Non-Indigenous Marine Species in Singapore: An Update

Zeehan JAAFAR

Department of Biological Sciences, National University of Singapore, Singapore

Non-indigenous marine and estuarine organisms are introduced to Singapore primarily through three invasion pathways—maritime activities, marine aquarium trade, and commercial fisheries. Established populations are few, when considering potential taxa entering the country through those pathways. Nineteen species are established in estuarine and marine habitats—two species of dinoflagellates, four species of molluscs, one species of polychaete, and twelve species of bony fishes. Discussions focus on ecological impacts of recently established non-indigenous populations.

Invited Talk 9

Do Singapore's Seawalls Host Non-Native Marine Molluscs

TAN Wen Ting

Department of Biological Sciences, National University of Singapore, Singapore

Urbanisation and the construction of artificial coastal structures such as seawalls have been implicated in the spread of non-native marine species due to their providing unoccupied niches for alien colonisation. Marine shipping is another important factor in the spread of non-native species as organisms can be transported on hulls and in ballast water. Singapore is potentially highly vulnerable to both these issues as its coastline comprises over 60% seawall and it is one of the world's busiest ports. The aim of this study was to identify the native, non-native, and cryptogenic molluscs found on Singapore's seawalls. To determine potential non-natives from within the Indo-Pacific, a set of attributes concerning the history, biogeography, detectability, human affinity, invasion path, biology, ecology, life-history, pre-history, evolution and genetics of species were applied to the molluscs collected. Four 'possibly introduced' species, i.e., *Cellana radiata*, *Siphonaria guamensis*, *Echinolittorina melanacme* and *Plicatula australis* were identified. The remaining species consisted of 41 native to Singapore and 20 cryptogenic species. The results from this study add to the increasing pool of literature showing that contrary to popular perception, there is a very low occurrence of non-native marine species in Singapore. We also discuss the possible reasons for this.

Invited Talk 10

New Record of an Invasive Marine Mussel *Mytella strigata* (Bivalvia: Mytilidae) in Singapore

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The American brackish-water mussel *Mytella strigata* (Hanley) (Bivalvia: Mytilidae), also known as *M. charruana* (Orbigny), is reported from Singapore for the first time. In 2016, a survey of intertidal hard structures in the East and West Johor Straits in Singapore revealed an almost ubiquitous presence of this species in high mean densities up to 124 ± 32 individuals 25 cm^{-2} along the shoreline. Subtidal nets employed by floating fish farms were also fouled with this mussel, often to the exclusion of other organisms including the native Asian green mussel *Perna viridis*. Size-frequency analyses of shells indicated the presence of both juveniles and adults. Juveniles are characterised by having a mottled greyish brown and black surface pattern on their shells. The adults, reaching 50 mm in shell length, generally have a thick dark greenish brown to almost black periostracum, but bright green and olive green individuals, some with distinctive green streaks, have also been observed, pointing to substantial intraspecific variation in shell colour. Preliminary observations suggest competition of space with *P. viridis* (Mytilidae) and the alien Caribbean black striped mussel *Mytilopsis sallei* (Dreissenidae). The recent appearance of *M. strigata*, whose native distribution includes the Mexican, Peruvian, Brazilian and Argentinian coastlines of Central and South America, is a new introduction to Singapore. The species may have been transported via fouling comprising native populations in the Americas, or from the Philippines where there are already established populations of *M. strigata*.

Invited Talk 11

Geographic Spread of an Alien Aquaculture Species, *Penaeus vannamei* and their Ecological Impacts in Eastern Thailand

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The rapid expansion of an alien species outside of its native range via aquaculture raises ecological concerns, especially if the escapees establish self-sustaining feral populations. *Penaeus vannamei* is one of the most cultured marine shrimp species in the world and was introduced to Thailand in the early 2000's for aquaculture. Annual production of *P. vannamei* has reached more than 300,000 metric tons since 2005. During 2005 to 2010, we monitored the geographic spread of *P. vannamei* along the eastern coast of Thailand and assessed some possible ecological impacts, namely the prevalence of a *P. vannamei*-specific pathogen (TSV) in wild-caught *P. vannamei* and local shrimp species, and some *P. vannamei* behaviors that may provide ecological advantages over native shrimp species. We observed larger and more mature wild-caught *P. vannamei* in offshore areas in 2009–2010 (TL 14.62 ± 1.54 cm) than at a river mouth in 2005–2007 (10.21 ± 1.59 cm). We detected the presence of TSV in nearly all six local species examined, with prevalence ranging from 3.82% to 13.91%. *P. vannamei* is an active swimmer similar to a local species, *P. merguensis*. Survival of *P. vannamei* in aquarium experiments with a predator (i.e. seabass) and varying turbidity levels and refuge cover was similar to that of *P. merguensis*. However, in an experiment with varying substrate types, *P. vannamei* had significantly higher survival compared to *P. merguensis*. Our results suggest that co-occurring species and potential predators may not provide selective pressure against *P. vannamei* in the wild.

Invited Talk 12

The Current Status and Management of the Golden Apple Snail in Vietnam

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Golden apple snail (GAS) originating from Central and South America have been imported into Vietnam from early 1985 to 1988 in the last century with the intention of farming for human food. Not long after that, GAS quickly spread to most freshwater ecosystems in the country, becoming one of the serious threats to agriculture (especially rice and spinach) in Vietnam. Two GAS species have been identified in Vietnam, *Pomacea canaliculata* and *P. maculata*. According to a report from the Department of Plant Protection (December 26 2006), 242,663 hectares were heavily infected with GAS. They are consuming a large expenditure for elimination. Currently, there is no single measure to effectively prevent the development of GAS. The Integrated Pests Management must to be applied to mitigate the impacts of these two species of snails.

Invited Talk 13

The 'Unseen' Invader has Settled Down: Observations on *Arctodiaptomus dorsalis* in Philippine Lakes

Rey Donne S. PAPA

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Non-indigenous zooplankton research in the Philippines had been virtually non-existent in the past, since most efforts on the taxonomy and distribution of zooplankton have not even considered their incursion in the archipelago and potentially detrimental impacts on local fauna. In 2011, efforts had been initiated to document the diversity of calanoid copepods in Philippine lakes, which had only been pegged to a measly seven species in spite of the long history of research on copepod taxonomy in the country. By 2016, the Neotropical calanoid copepod *Arctodiaptomus dorsalis* had been recorded from 23 out of 32 freshwater ecosystems, instead of discovering novel species or new records for native and or endemic calanoid species. Furthermore, the occurrence of *A. dorsalis* in freshwater habitats that used to be inhabited by native and / endemic calanoid copepods raised concerns that it has begun to displace local calanoid fauna, even before efforts had been made to document their diversity and species composition. Since the initial discovery of this non-indigenous zooplankton in the Philippines, several studies had been conducted to document its distribution and occurrence, life history, morphometric and reproductive traits and development. This paper presents the results of studies that had been conducted on *Arctodiaptomus dorsalis* in the Philippines, including its first recorded occurrence in a groundwater ecosystem in the northern part of Luzon Island and notes on its distribution which mainly centered on aquaculture areas in different parts of the archipelago, temporal variability of morphometric and reproductive traits in relation to the reduction of aquaculture in a volcanic caldera lake (Lake Taal), a comparison of its morphometric and reproductive traits with a native calanoid species (*Mongolodiaptomus birulai*) and the effect of temperature variations on the clutch sizes and prosome lengths of *A. dorsalis* populations in a cluster of seven maar lakes in Southern Luzon Island. Our findings suggest that *A. dorsalis* populations have spread mostly in inland water bodies that are heavily utilised for aquaculture, which explains their distribution pattern that is mainly concentrated in southern Luzon and southwestern Mindanao. Furthermore, in all lakes where populations of *A. dorsalis* had been documented, it was only in Lake Taal where populations of *A. dorsalis* were found to co-exist with another calanoid species (*Pseudodiaptomus brehmi*), otherwise, *A. dorsalis* seemed to favor being the sole calanoid species in any given zooplankton community. It also easily established itself due to the suitability of limnological conditions for their sustained growth and survival, including the high year-round productivity of all the lakes studied and the higher abundances and larger clutch sizes of *A. dorsalis* compared to native species, which may also explain why *A. dorsalis* had been able to displace native species from their usual habitats.

Invited Talk 14

Introduced Decapod Crustaceans in Indonesia's Inland Waters

Daisy WOWOR

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Introduced or alien freshwater decapod crustaceans from Indonesia's inland waters were recorded from several previous and an ongoing surveys. There were two species of decapods found from the inland waters, i.e., one freshwater shrimp, *Macrobrachium lanchesteri* (Palaemonidae) and one freshwater crayfish, *Cherax quadricarinatus* (Parastacidae). The two alien species were mainly documented from lacustrine environment, however, *M. lanchesteri* can also be encountered in moderate to slow flowing parts of riverine systems. The shrimp was accidentally introduced to the water bodies through commercial stocking of alien fishes aimed at improving the productivity of the waters. In some lakes and irrigation canals, the shrimp became very dominant and caused the extinction of the native inhabitants. While the crayfish was brought in through the ornamental fish trade and aquaculture activities (because of its commercial value), there are no records of impacts on the native ecosystem thus far, although some fish-pond owners complain of leakages caused by the crayfish's burrowing behaviour.

Invited Talk 15

Invasive Apple Snails, *Pomacea* spp. as Pest in Irrigated Rice: Present Status, Impact and Management

Ravindra Chandra JOSHI

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University of the South Pacific, Fiji

This presentation will give an overview of the present status of invasive apple snails, most notably *Pomacea canaliculata* and *Pomacea maculata*, and their spread to the areas outside of their native ranges. The global, regional, and national (local) impact of their invasion on rice production system will be discussed. In addition, the steps to manage or control them in rice ecosystems in the changing climate scenario and prevailing crop management practices will be discussed. Lastly, the author would like to open discussions on designing future policies and programs centered on an integrated and collective approach to effectively manage invasive apple snails *Pomacea* spp. in the invaded countries. This will include proposals on international partnerships, and global information e-databases access and development.

Invited Talk 16

Potential Effects of Climate Change in Cognitive Abilities in an Invasive Fish

Kit MAGELLAN

The University of Hong Kong, Hong Kong SAR, China

Two of the greatest pressures on biodiversity are climate change and biotic invasions. In aquatic ecosystems, a particularly important climate change influence is increased temperatures as the ectothermic species that inhabit them are vitally dependent on temperature. One effect of temperature on invasive species that has received little attention is changes in cognitive abilities. A key attribute of successful invasive species is behavioral flexibility and temperature has been shown to enhance learning and innovation in several taxa which may influence the selection pressures on both native and invasive species. An ideal model species with which to investigate this is the mosquitofish, *Gambusia affinis*. This highly adaptable fish has been introduced into over 50 countries, including China and Hong Kong, as mosquito control agents, and are considered among the 100 worst invasive species worldwide. Most research on the effects of *G. affinis* invasion has been done in temperate regions, although tropical habitats, with their high aquatic biodiversity and conditions that allow year round breeding and therefore rapid population growth, may be under the greatest threat. I investigated the effects of increasing temperatures in a series of laboratory experiments in which fish born and reared at a range of temperatures were tested in different learning tasks. Early results indicate that fish quickly learned to locate a novel food source and that performance improved over time. Males and females from different temperatures show different patterns of responses. However, the precise effects of temperature are inconsistent thus far and pending further investigation and analysis.

Invited Talk 17

Investigating the Ecology of Invasive Alien Species in Singapore's Fresh Waters

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Numerous alien species thrive in Singapore's freshwater environments. Despite the potential threats posed by invasive alien species, the ecology of these freshwater alien species has been largely overlooked—partially because of their general confinement to artificial/modified habitats (e.g., reservoirs, urban ponds, canals, rural streams) that have few native species. The lack of ecological studies, however, has led to poor understanding of the possible impacts on the natural environment; this is a concern given the growing numbers of freshwater alien species in Singapore, and their increasing proximity and/or accessibility to natural freshwater habitats (e.g., forest streams), which are important refugia for native biodiversity. Since 2010, the Freshwater and Invasion Biology Lab (FIB Lab) at the Department of Biological Sciences, National University of Singapore, has attempted to shed light on freshwater invasive alien species in Singapore through various ecological studies at organismal to community/ecosystem levels. Besides investigating interactions with (or potential impacts on) native species, the studies also aimed to identify and quantify the distributions, pathways, and spread of alien species (together with their influencing factors), as well as to improve our understanding of invasiveness, and predict invasions in Singapore. This talk will provide a brief overview of freshwater invasion ecology research carried out by the FIB lab, highlighting recent work on fishes, amphibians, and prawns, as well as on resistance/vulnerability of forest streams to invasion.

Invited Talk 18

Impacts of Introgression on Natural Communities

Keren SADANANDAN

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Introgression is the transfer of genetic material from one species to another via hybridisation. This process is increasingly recognised as a pervasive phenomenon in evolutionary processes such as speciation and in the introduction of novelty into the gene pool, but also in loss of allelic diversity. Anthropogenic habitat destruction has led to higher incidences of introgression across several taxa, including crocodiles, wolves and birds. Modern genomic tools have been used to detect signals of introgression and examine their effects on both declining and expanding populations.

Invited Talk 19

Bioeconomic Modeling to Support Risk Analysis for Invasive Species

L. Roman CARRASCO

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Managing invasive species cost-effectively requires the consideration of the probability of introduction, establishment and spread of the invasive species and the subsequent potential impacts that it could generate. Whereas tools have been developed to quantify the risk of invasive species in temperate regions, these are very rare in tropical environments and especially in Southeast Asia. In this talk I will present a regional decision support scheme developed for invasive pest risk analysis in Southeast Asia. I will highlight the main differences of this scheme with respect to high-income temperate nations counterparts. I will also talk about the estimation of economic impacts by invasive species in the region and the role of international trade as a telecoupling force that creates impacts in distant regions through invasive species introductions.

Invited Talk 20

Exotic Aquatic Macrophytes in Tropical Lakes: Management and Potential Applications

Darren Zong Han SIM

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Aquatic macrophytes are important components of lentic ecosystems by having profound effects on the physical environment, trophic structure, and water clarity. However, some species, such as water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillata*), are noxious exotic weeds in many geographical regions and have caused considerable socio-economic and ecological impacts. Despite these risks, exotic species can be useful for improving the environment under carefully managed scenarios. The usefulness of these invasive species may be attributed to their higher growth rates, allelopathic interactions, and environmental adaptability—traits that could have useful applications. While frequently considered undesirable in managed habitats, exotic aquatic macrophytes can occasionally be beneficial for ecosystem functioning, or as part of a restoration process. Usage of exotic macrophytes is especially relevant to Singapore, in which reservoirs are novel habitats that do not support native aquatic flora adapted to cool, shaded, acid-water forest streams and freshwater swamps, but where a degree of ecosystem service is desired to improve water quality for public use. This presentation discusses the state of exotic aquatic macrophyte introductions in lentic ecosystems, with a focus on their potential benefits and applications.

Invited Talk 21

Measuring the Effects of Temperature and Food Concentration on *Arctodiaptomus dorsalis*: The Importance of Laboratory Culture Studies in Invasive Copepod Research

Dino T. TORDESILLAS

University of Santo Tomas, Philippines

Life history studies on invasive alien species (IAS) have been deemed significant in order for researchers to better understand how these organisms adapt to new abiotic and biotic conditions, affect their new habitats, and how natives evolve in response to the presence of these invaders. Although copepods are one of the more common aquatic IAS, few works have detailed the biology of these microcrustaceans in ecosystems where they have been introduced, and have successfully established populations. Such was the case for *Arctodiaptomus dorsalis*, which was studied in Florida, USA in the early 1980s, but has not been previously studied in the laboratory in the Philippines despite its documented widespread distribution in the country's inland waters. This paper reports the results of laboratory experiments on the life history of *A. dorsalis*, and how these culture studies complement observations in the field. Results show that at a temperature of 30°C, *A. dorsalis*' development times were significantly shorter, but at 35°C, adult survival and hatching success were greatly reduced. Individual mean oxygen consumption rates also more than doubled from 2.43 $\mu\text{L day}^{-1}$ at 20°C to 5.60 $\mu\text{L day}^{-1}$ at 35°C. On the other hand, with food concentrations ranging from 4×10^3 cells mL^{-1} to 2×10^5 cells mL^{-1} , egg production rates increased from 3.00 to 7.54 eggs female day^{-1} , while interclutch durations and latency times decreased from 2.00 to 1.71 days and 1.58 to 0.71 days, respectively. Fecundity also increased from 3.4 to 59.2 eggs female $^{-1}$ with increasing food concentration. All these numbers suggest that, in freshwater habitats with a maximum temperature of 30°C and high algal cell concentration, *A. dorsalis* is capable of developing faster and has higher rates of survival while producing more eggs at shorter spawning intervals.

Invited Talk 22

Current Knowledge of an Invasive Alien Species, *Gambusia affinis*, in Kenyir Reservoir

Amiruddin AHMAD

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Mosquitofish, *Gambusia affinis* is a well-known notorious invasive alien species (IAS), has been widely demonstrated to negatively impact aquatic ecosystems around the world. This species was recently reported in Kenyir Reservoir, one of the biggest impoundments in Southeast Asia, that harbours many native species with high commercial values. The current distribution of *Gambusia affinis*, which is apparently limited to areas with anthropogenic disturbance and around lake margins, suggests the fish is yet to be widely established. Comparison of trophic level information suggests this species may compete with several sympatric species, the most notable being the tin foil barb, *Barbonymus schwanenfeldii*, which is commercially valuable. Further study is recommended for the formulation of appropriate conservation measures.

Invited Talk 23

Movement of Frogs and Turtles Relevant to Bioinvasions on Borneo

Indraneil DAS

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Invasive herpetofaunas on Borneo may be classified as non-native to the island or non-native to specific habitats. Frogs that have benefited from human activities have expanded their ranges. One example is *Kaloula pulchra*, known till the turn of the century from two isolated localities, and having then spread across the northern coast by the first decade of 2000, and is now widespread in Sarawak State. Other exotic frogs have been less successful: established populations, for one, exist in the immediate vicinity of farms (*Hoplobatrachus rugulosus*) or have failed to establish as escapees (e.g., *Lithobates catesbeianus*). Less well known is the invasion of local species into primary forests. Field observations show that creation of roads and disturbance along rivers eventually permit access to forested areas. Specifically, high temperatures associated with standing bodies of water provide suitable breeding areas for such species. Invasive reptiles include *Calotes versicolor* (introduced at the turn of the century) and *Trachemys scripta* (earliest introduction at least by the late 1990s); the first, probably introduced with imported plants, the second from the pet trade.

Field observations on *Megophrys nasuta* and *Heosemys spinosa* were made to gain insights on these surrogates of their respective groups. Frogs were marked with passive integrated transponders; turtles were radio-tracked. Adult frogs show site-fidelity, while juveniles ranged up to 335m over a three-day period. Adult turtles showed restricted movement, changing resting sites by under 44m, and occupying the same shelter for much of the 60 days of observation.

These studies indicate relatively low mortality in the rainforest herpetofaunas, except for juvenile frogs. Less well understood are movements of invasive species, and emphasise the need for more studies on the introduced herpetofaunas.

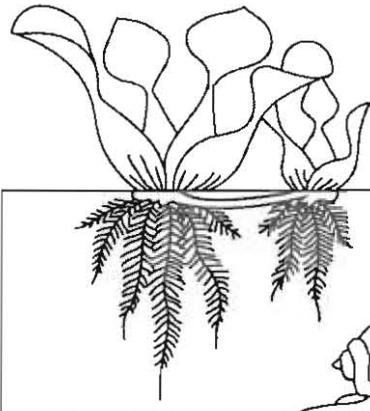
Invited Talk 24

The Singapore Crayfish Story: Understanding the Drivers and Impacts of the *Cherax quadricarinatus* invasion

ZENG Yiwen

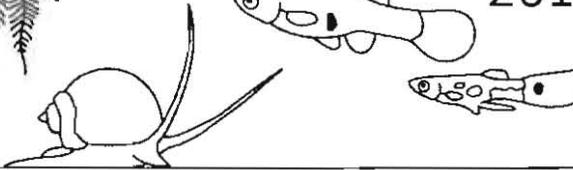
Department of Biological Sciences, National University of Singapore, Singapore

While most aquatic alien species in Singapore are restricted to artificial or highly modified environments, one species, *Cherax quadricarinatus* (Australian redclaw crayfish), has successfully invaded a number of natural forest streams. Forest streams contain the majority of the country's native freshwater species, which increases the severity of potential impacts associated with the alien crayfish. This talk focuses on recent efforts aimed at quantifying drivers and impacts associated with the spread of *C. quadricarinatus* in Singapore. Utilising field studies, along with statistical techniques (e.g., structural equation modeling), environmental filtering was identified as the key factor affecting crayfish spread. *Cherax quadricarinatus* was also found to potentially cause declines or displacements in the native lowland freshwater crab (*Parathelphusa maculata*) populations. To identify potential mechanisms of such species displacements, stable isotope analyses and behavioral experiments were additionally employed. These studies indicate that while *C. quadricarinatus* is unlikely to compete with *P. maculata* over a common food source, it can prey upon such native species. The studies also suggest that overall size asymmetries between the two decapods can also drive competitive exclusion of *P. maculata* from a limited resource (shelter). The identification of such impacts represents an important first step in the development of relevant management and conservation strategies.



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