20th International Conference of Aquatic Invasive Species
Fort Lauderdale, Florida; October 22–26, 2017

Aquatic invasive species in Singapore:
Perspectives from a highly urbanised tropical city

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UF IFAS UNIVERSITY of FLORIDA

Conference Host
Lyn Gettys, University of Florida, IFAS

Invasive Species Centre

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Canada

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RESEARCH INSTITUTE
NATURE AND FOREST

ONTARIO POWER GENERATION

Marrone Bio Innovations

AERF
Aquatic Ecosystem Restoration Foundation

US Army Corps of Engineers.

The FIB lab established 2010 …

Scope

BACKGROUND
FROM PATHWAYS TO IMPACTS
WHAT NEXT?

A little context

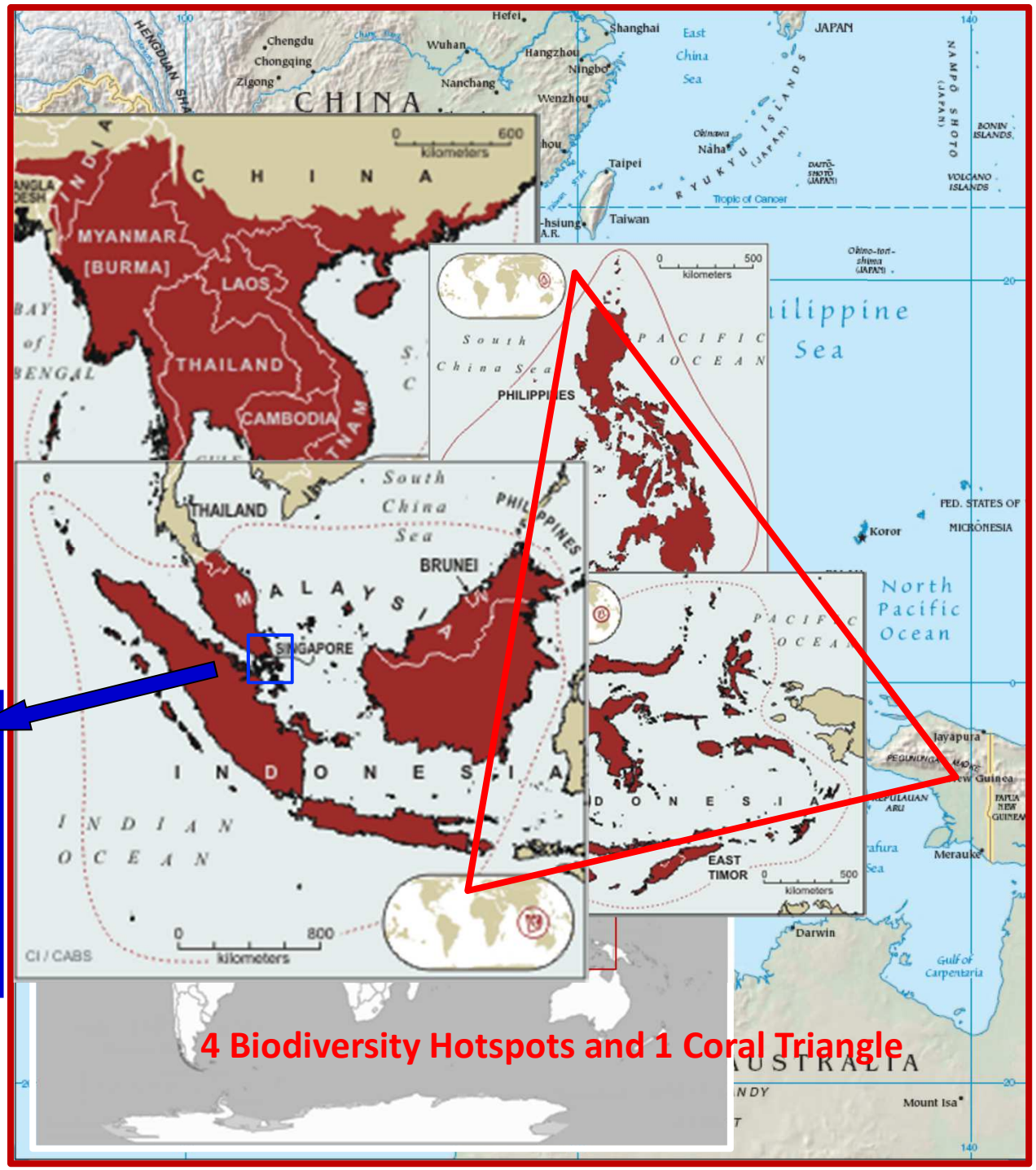
BACKGROUND

Background

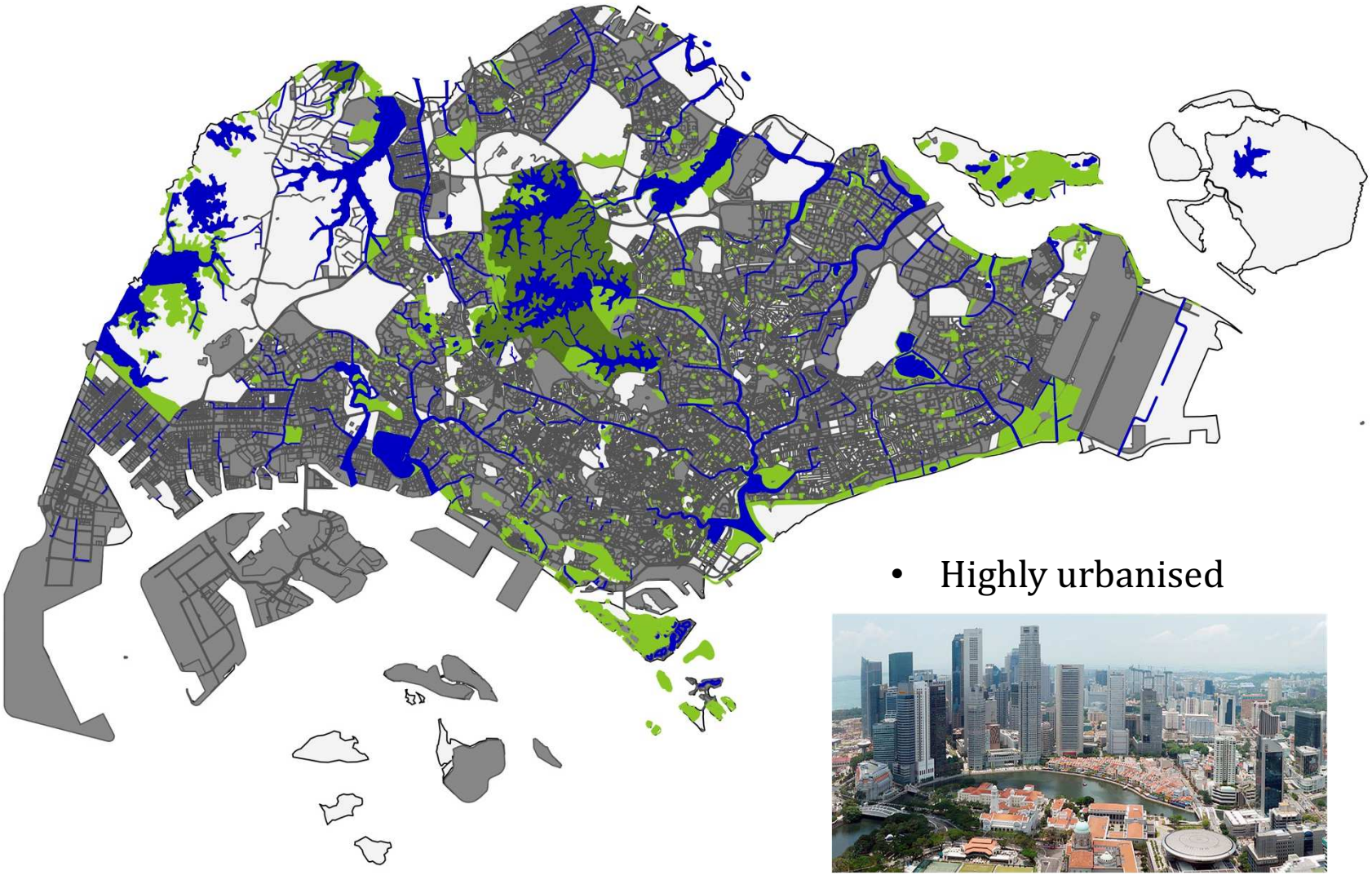
Where is Singapore?

- Southeast Asia
- ~1 deg N of equator
- Island city state
- Land area ~719 km^2 (278 sq mi)

...very small



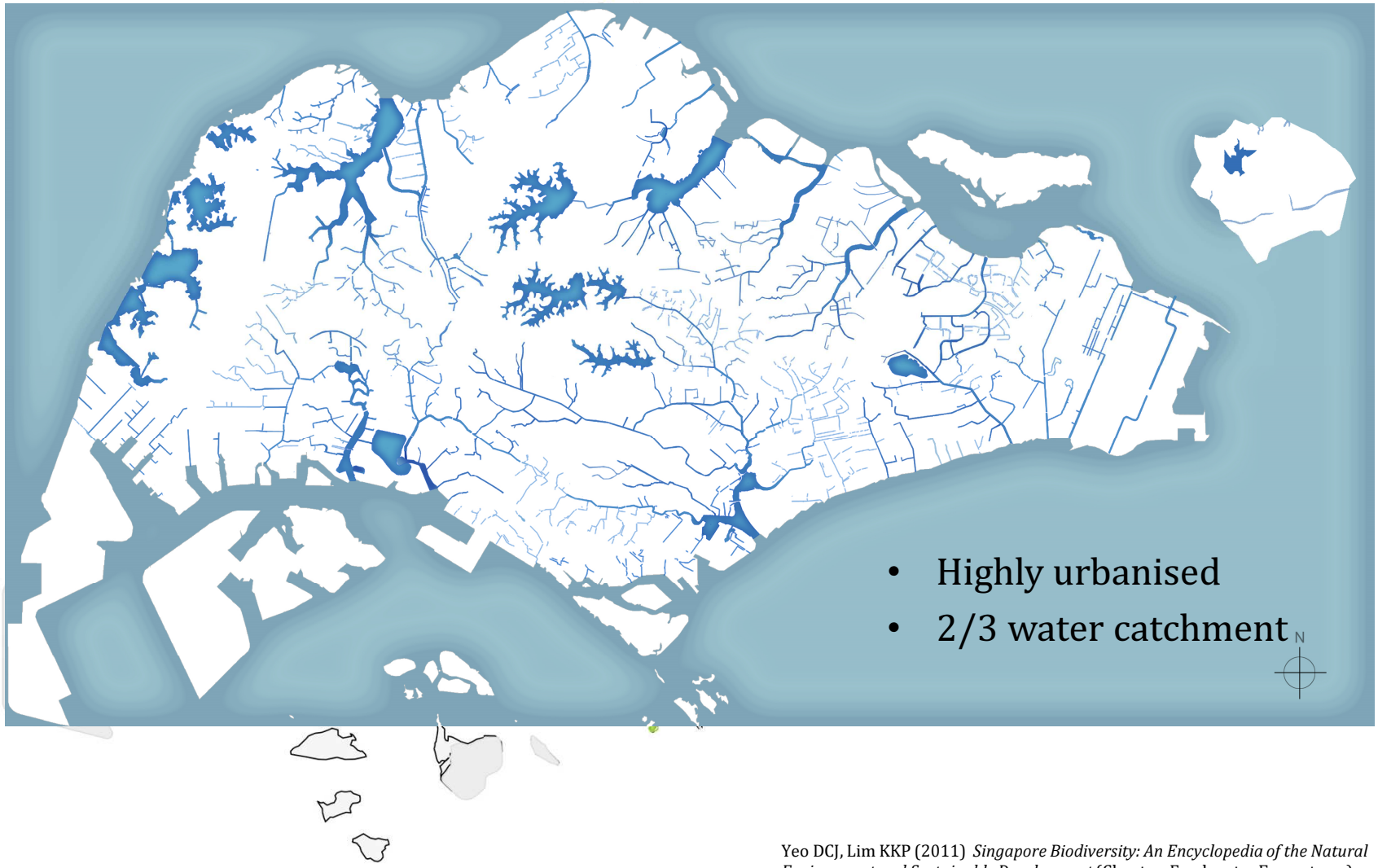
Singapore, a city in a garden



- Highly urbanised

Background

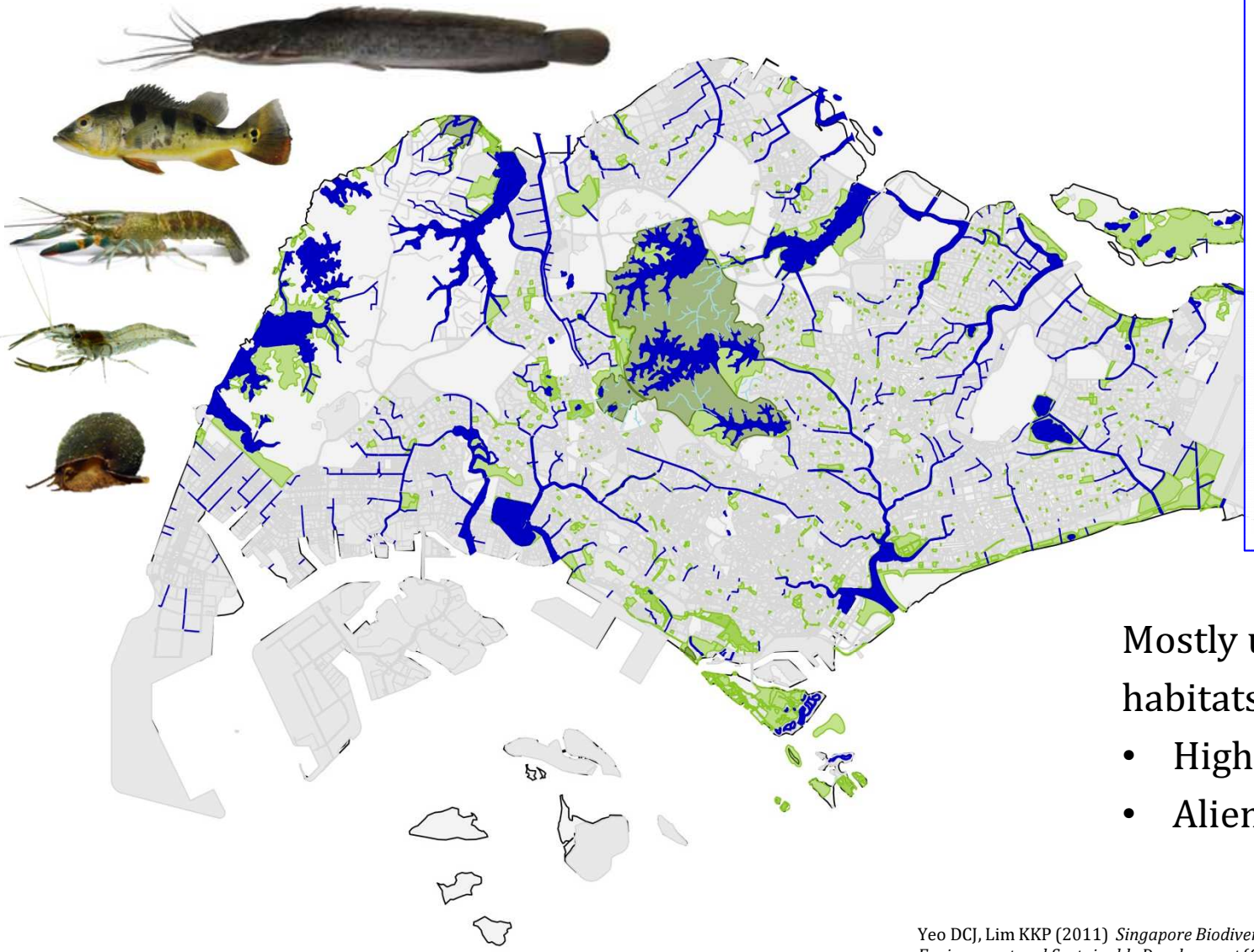
Fresh waters of Singapore:



Yeo DCJ, Lim KKP (2011) *Singapore Biodiversity: An Encyclopedia of the Natural Environment and Sustainable Development* (Chapter: Freshwater Ecosystems);
Yeo DCJ, Wang LK, Lim KKP (2010) *Private Lives: An Exposé of Singapore's Freshwaters*

Background

Fresh waters of Singapore:
urban freshwater habitats



Reservoirs

Urban Ponds

Drains/Canals

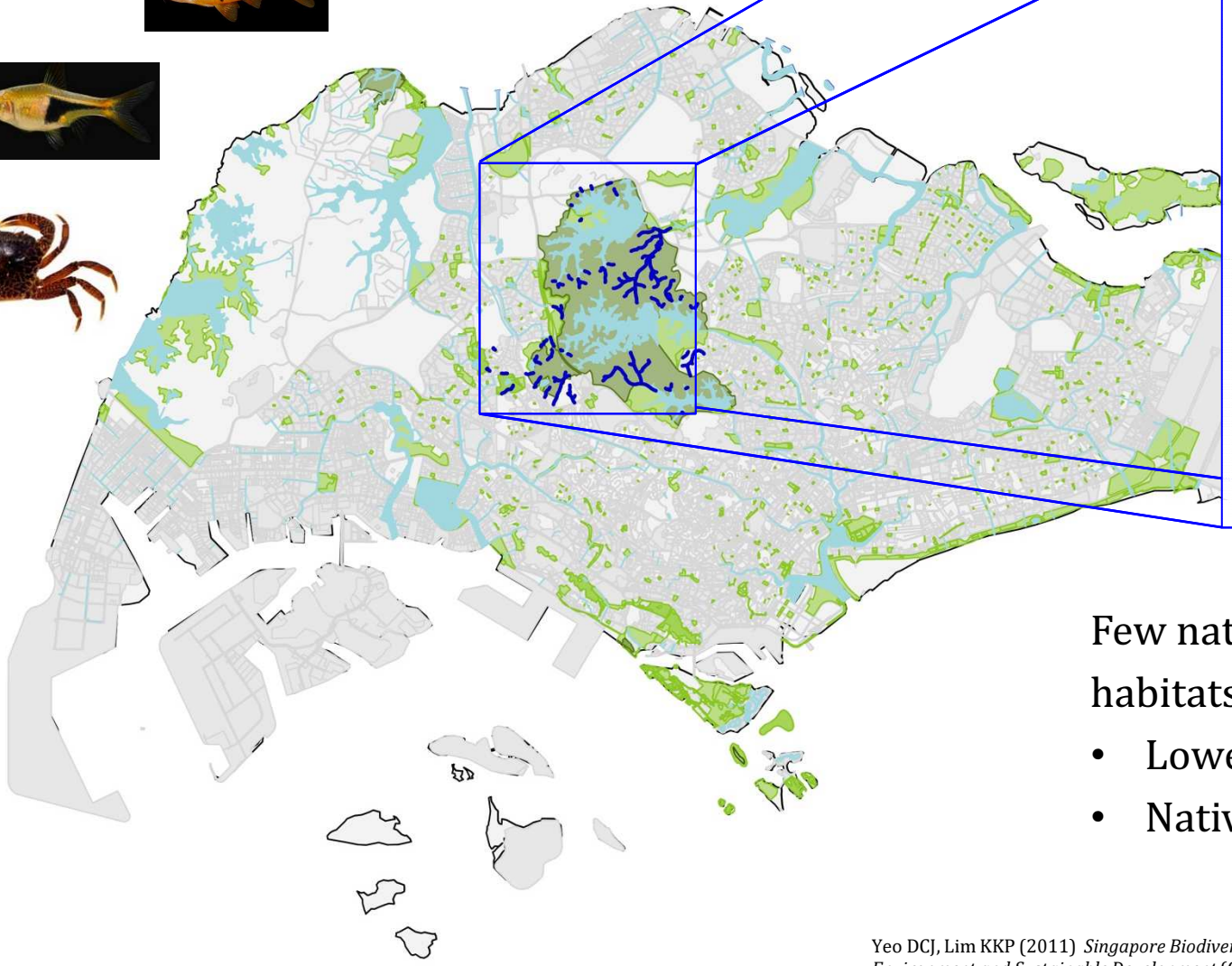
Mostly urban freshwater habitats

- Higher pH, temp
- Alien species

Yeo DCJ, Lim KKP (2011) *Singapore Biodiversity: An Encyclopedia of the Natural Environment and Sustainable Development* (Chapter: Freshwater Ecosystems);
Yeo DCJ, Wang LK, Lim KKP (2010) *Private Lives: An Exposé of Singapore's Freshwaters*

Background

Fresh waters of Singapore:
natural freshwater habitats



Freshwater swamp

Forest streams

Rural streams

Few natural freshwater habitats

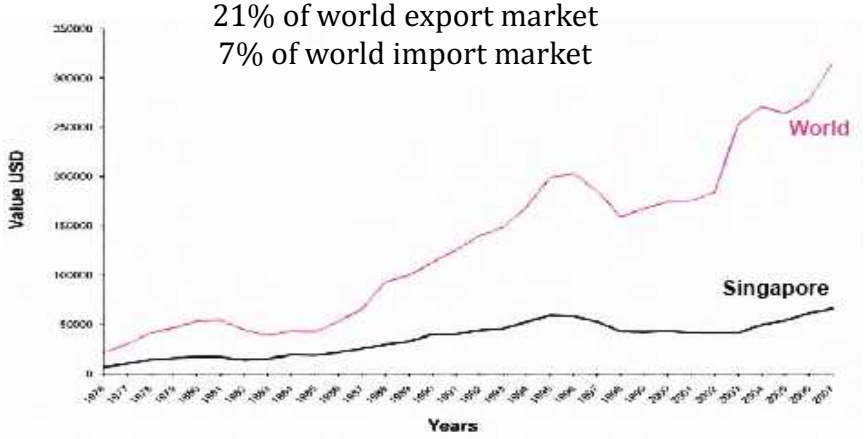
- Lower pH, temp
- Native species

Yeo DCJ, Lim KKP (2011) *Singapore Biodiversity: An Encyclopedia of the Natural Environment and Sustainable Development* (Chapter: Freshwater Ecosystems);
Yeo DCJ, Wang LK, Lim KKP (2010) *Private Lives: An Exposé of Singapore's Freshwaters*

Singapore…a hotbed for freshwater invasions

International/ regional trade hub

Ornamental fish trade
21% of world export market
7% of world import market



Among the world's busiest ports

2.5 billion gross tonnage in 2015

- >325 exotic vascular plants
- >163 introduced animal species
  - mostly aquatic—mostly freshwater:
    - >50 fishes
    - 5 decapod crustaceans
    - 29 molluscs
    - 4 amphibians
    - 18 reptiles

Including some of the World's Worst Invasive Species

Asian clam
Corbicula fluminea

Golden apple snail
Pomacea sp.

Yeo & Chia 2010 *Cosmos*; Lok et al 2010 *Cosmos;* Various authors 2010–2016 *Nature in Singapore;* Monticini 2010 *FAO*

Background

- Alien species
  - No specific studies prior to 2010 (apart from new records)
  - Ecology and impacts poorly known
  - Favour urban (artificial/modified) habitats—but still a potential threat to native biodiversity and ecosystems…

Typical aquatic alien species habitat

Biol Invasions
DOI 10.1007/s10530-007-9094-0

ORIGINAL PAPER

Feral populations of the Australian Red-Claw crayfish (*Cherax quadricarinatus* von Martens) in water supply catchments of Singapore

Shane T. Ahyong · Darren C. J. Yeo

Australasian red-claw crayfish (*Cherax quadricarinatus*)

Biol Invasions
DOI 10.1007/s10530-009-9663-5

INVASION NOTE

Stingers in a strange land: South American freshwater stingrays (Potamotrygonidae) in Singapore

Heok Hee Ng · Heok Hui Tan · Darren C. J. Yeo · Peter K. L. Ng

home. THE STRAITS TIMES FRIDAY, MARCH 26 2010 PAGE C5

Stingrays breeding in Upper Seletar

Non-native species with venomous sting likely released into reservoir by hobbyists

By Grace Chua

IT IS official: Freshwater stingrays the size of dinner plates are breeding in at least one Singapore reservoir.

These barbed Motoro stingrays, native to South America, are lurking in the Upper Seletar Reservoir where sport fishing, kayaking and boat rides are allowed.

These fish, likely to have been released into the reservoir by fish hobbyists, can deliver venomous stings that can cause extreme pain and even death.

But national water agency PUB, the custodian of reservoirs, said that to date, there have been no reports of stingray injuries in Upper Seletar. Still, it advises kayakers to wear protective footwear and to launch their boats from a concrete pontoon instead of the shore.

PUB also urged fish hobbyists not to release non-native animals into the reservoir because, injuries aside, these creatures can upset the food chain there by feeding on native species, out-competing them for food and spreading diseases to which the local species are not immune.

Examples of non-native species that have established themselves in Singapore include the tomato or snakehead fish and the African walking catfish, both of which are voracious and aggressive.

Temm made the news in 1991 when they attacked the young swans in Botanic Gardens.

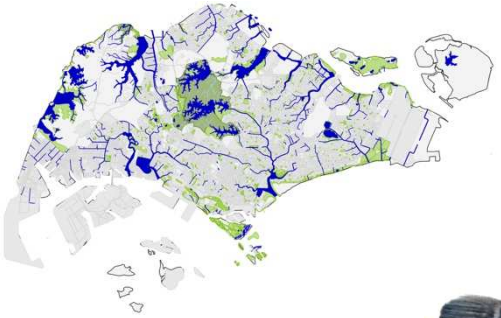
Local anglers and park staff have thus far known of the Motoro stingrays only anecdotally, but scientists from the National University of Singapore's Raffles Museum of Biodiversity Research have netted and identified them.

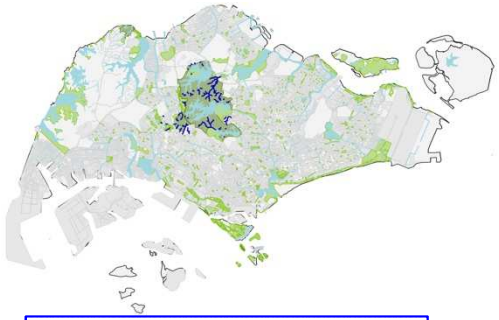
The Motoro stingray can deliver stings that can cause extreme pain and even death. Native to South America, it can measure nearly a metre from head to barbed tail.

This photo by a Straits Times reader shows a fisherman with a stingray at Upper Seletar Reservoir. There have been no reports so far of stingray injuries at the reservoir, says PUB.

S American freshwater stingray (*Potamotrygon motoro)*

Freshwater habitats

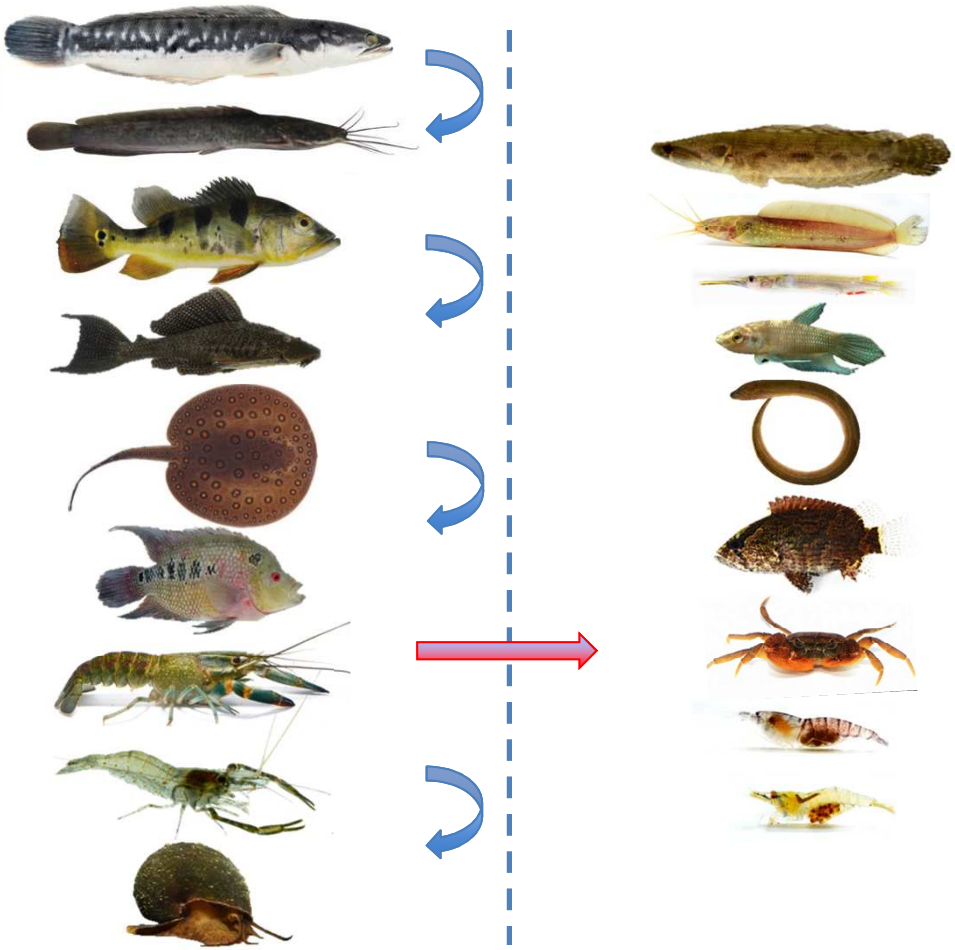




Reservoirs

Urban Ponds

Drains/Canals



Freshwater swamps

Forest streams

Rural streams

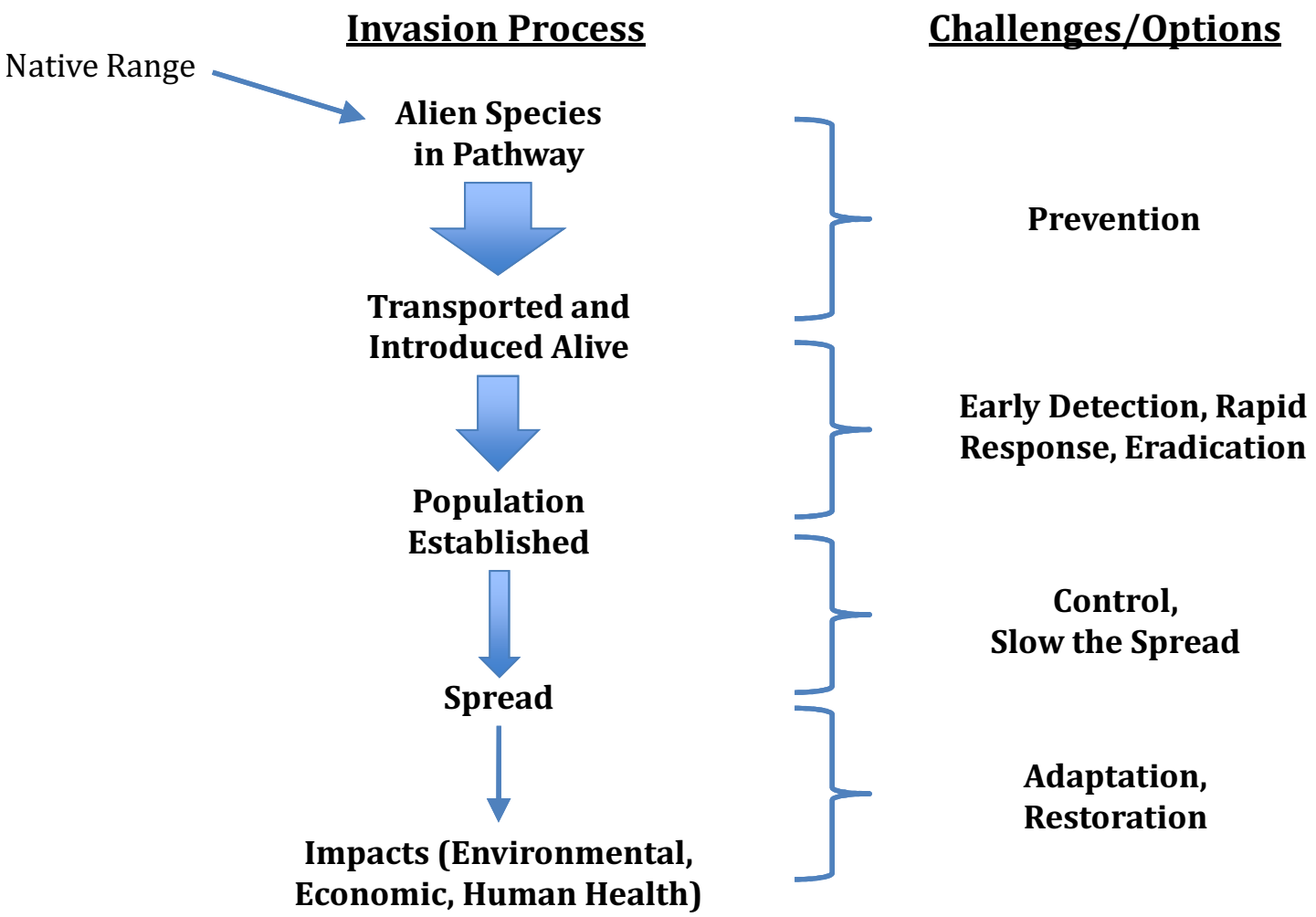
Urban / Aliens

Natives / Natural

From Pathways to Impacts

Aquatic invasions

Understand freshwater invasions → **Act on/Manage** freshwater invasions



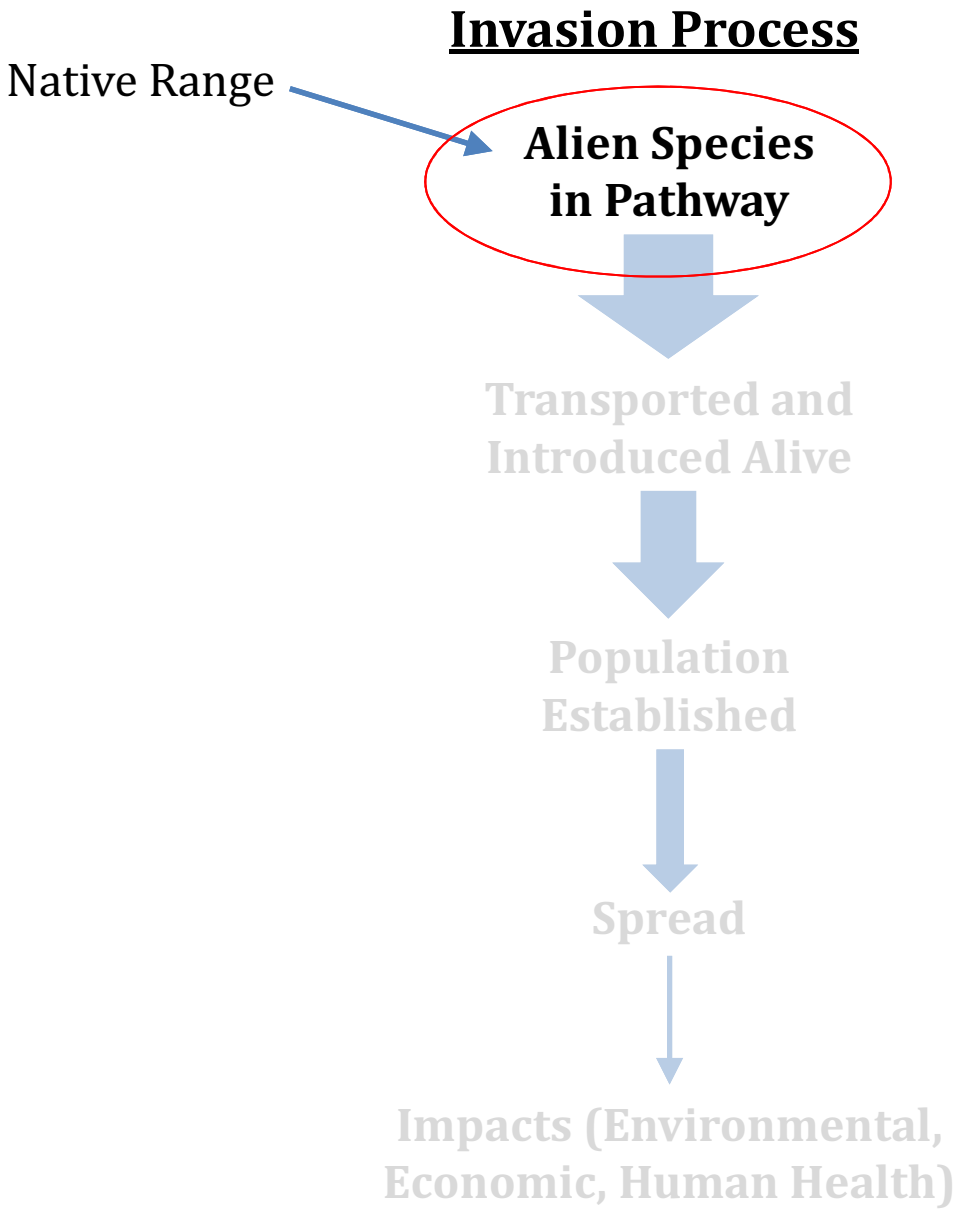
Lodge et al (2006) *Ecol Appl*

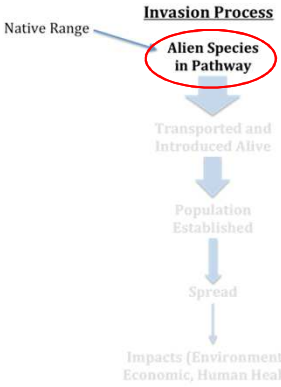
Work on aquatic invasives in Singapore

FROM PATHWAYS TO IMPACTS

From Pathways to Impacts

Aquatic invasions





Introduction pathways

Ornamental/aquarium

Hitchhikers

Fish feed

Live seafood

Biofouling

Ballast water

What species are involved?

Reliable checklists:

- Surveys (field and trade); lit reviews
- DNA barcoding (COI, 16S genes)
- Risk assessment (high risk BW species)

Many species remain in the pathways, i.e. not released into the wild…yet

Ng TH, Tan SK, Wong WH, ..., Yeo DCJ (2016) *PLoS ONE*
Low BW, Ng NK, Yeo DCJ (2013) *BioInvasion Records*
Yeo DCJ, Ahyong ST, Lodge DM, ..., Lane DJW (2010) *Biofouling*
Chong ESM, Teo SLM, Yeo DCJ (in prep)

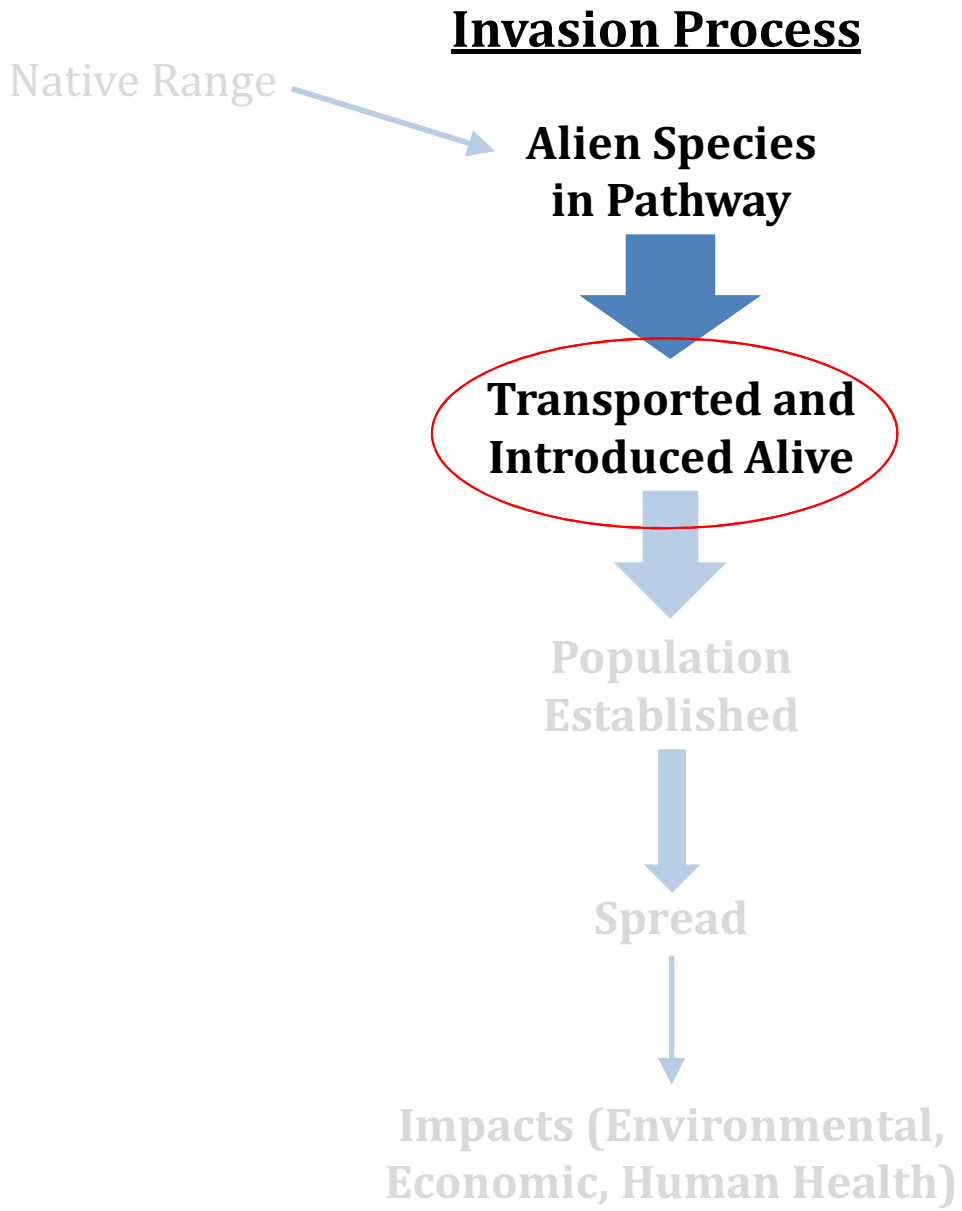
Introduction modes/vectors

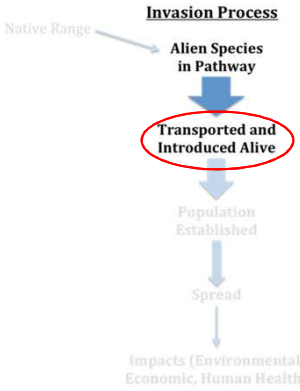
How do alien species actually move from the pathway into the wild in Singapore?

- Possible introduction modes
  - Unwanted/abandoned pets
  - Mercy/religious release
  - Biological control
  - Sport fishing releases
  - Bait
  - Farm escapes
  - Improper disposal of aquarium water

Yeo & Chia (2010) *Cosmos*

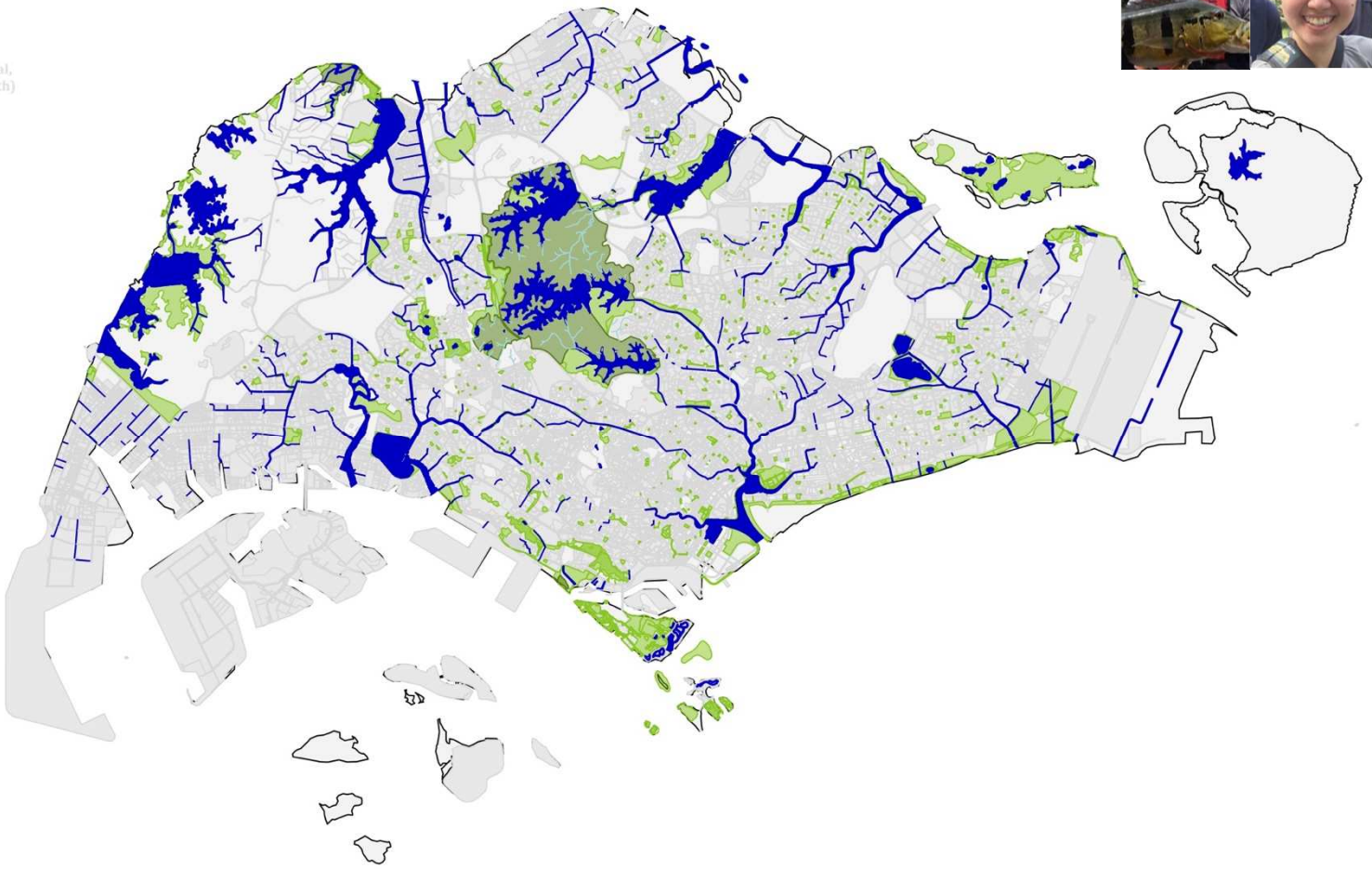
Aquatic invasions





Introduced species

Keeping track of new introductions



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Ng TH, Tan SK, Yeo DCJ (2014) *Malacologia*

Liew JH, Tan HH, Yeo DCJ (2012) *Nature in Singapore*

Ng HH, Tan HH, Yeo DCJ, Ng PKL (2010) *Biological Invasions*

Ng TH, Yeo DCJ (2012) *Nature in Singapore*

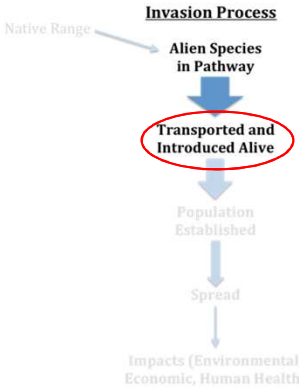
Yeo DCJ, Lim KKP (2010) *Nature in Singapore*

Tan SH, Yeo DCJ, Tan HH (eds) (2010) *Introduced species in Singapore.*

Yeo DCJ (2010) *Cosmos*

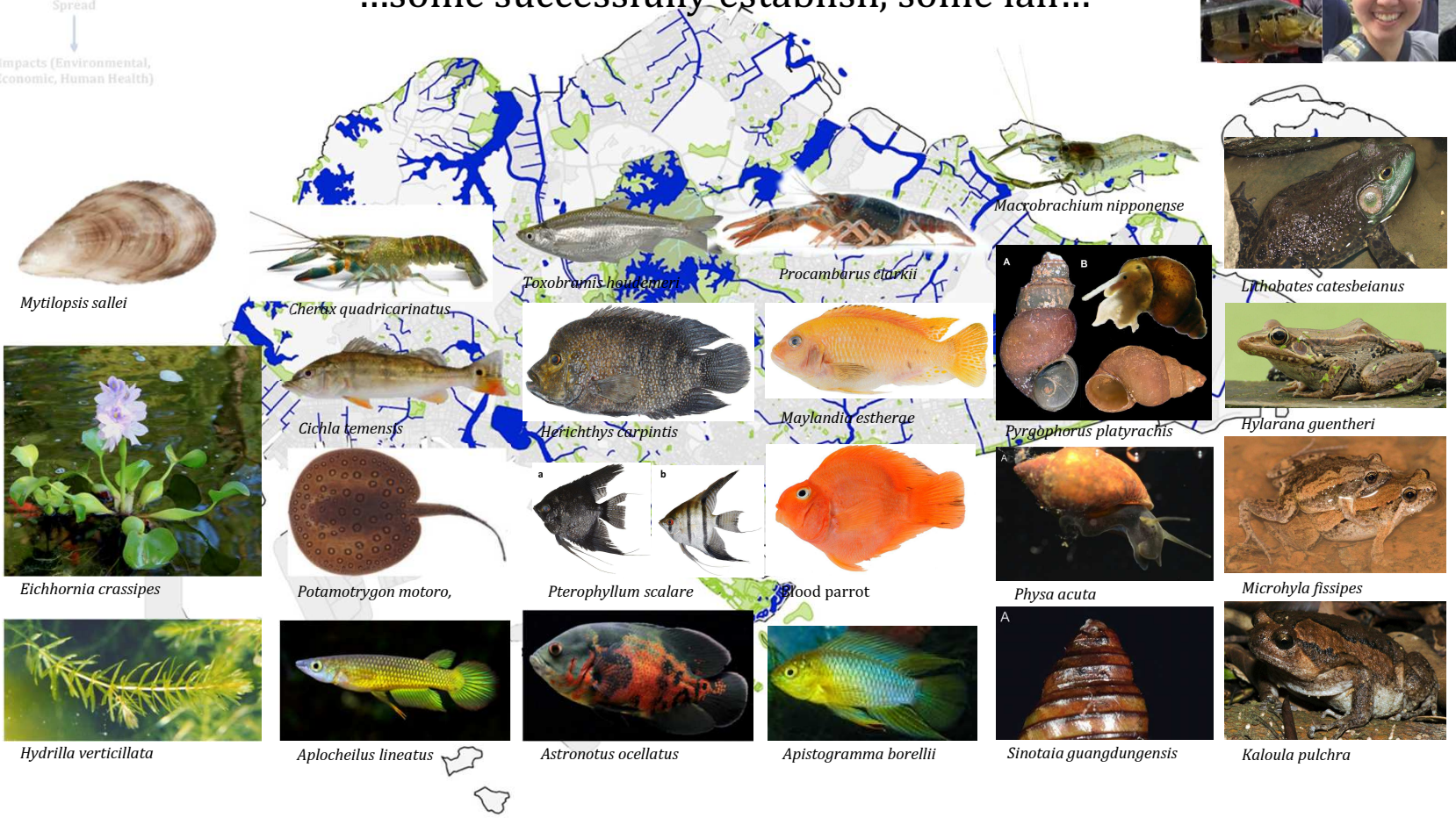
Yeo DCJ, Chia CSW(2010) *Cosmos*

Zeng Y, Yeo DCJ (in prep)



Introduced species

27 new records since 2010 (~3–4/year)
…some successfully establish, some fail…



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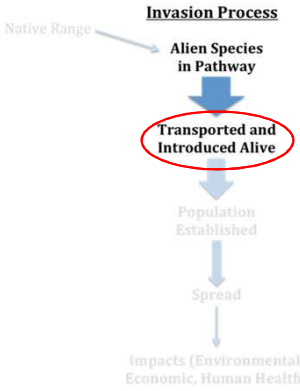


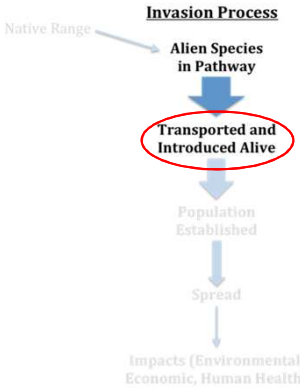
Introduced species

Some fail to establish, but are always around!

Red-eared slider
(*Trachemys scripta elegans*)

American bullfrog
(*Lithobates catesbeianus*)

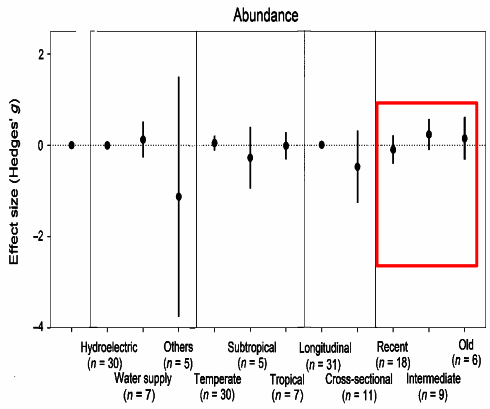
Ng TH, Yeo DCJ (2012) *Nature in Singapore*
Ng TH, Lim KKP (2010) *Cosmos*



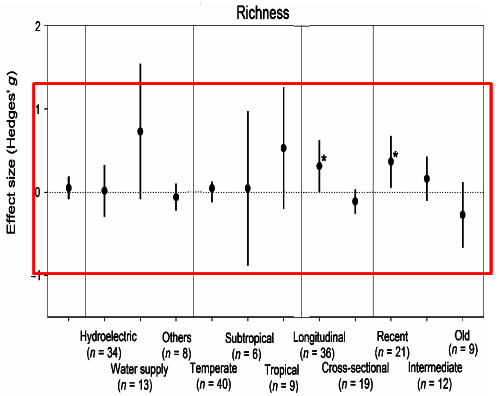
Introduced species

… contributing factors:

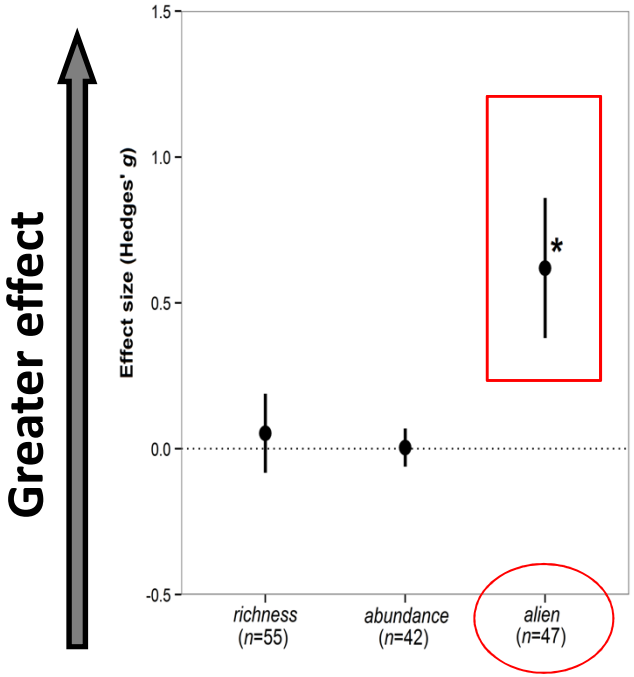
Damming



Damming: little change in species richness



Damming: significantly increase alien species proportions



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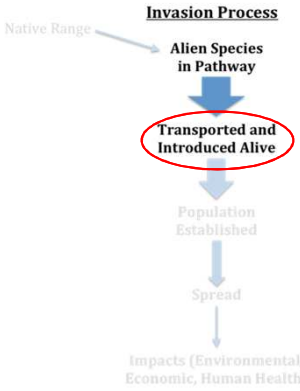

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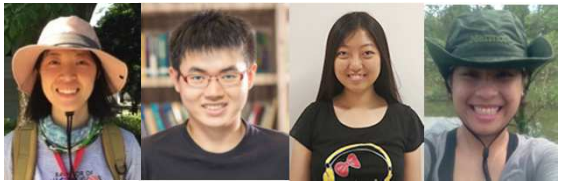
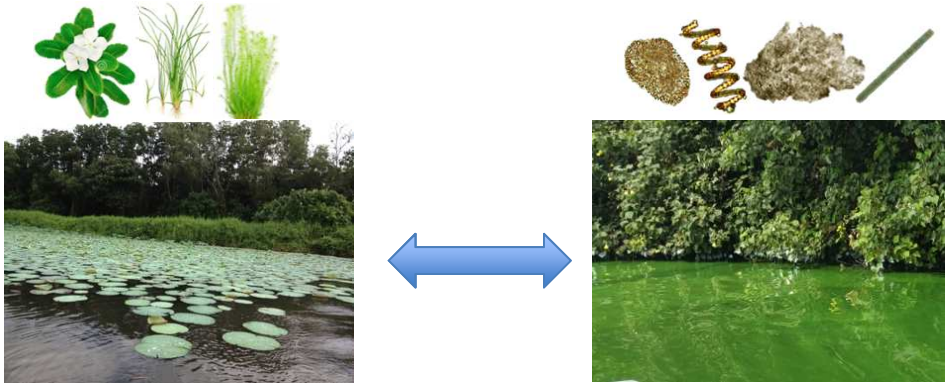
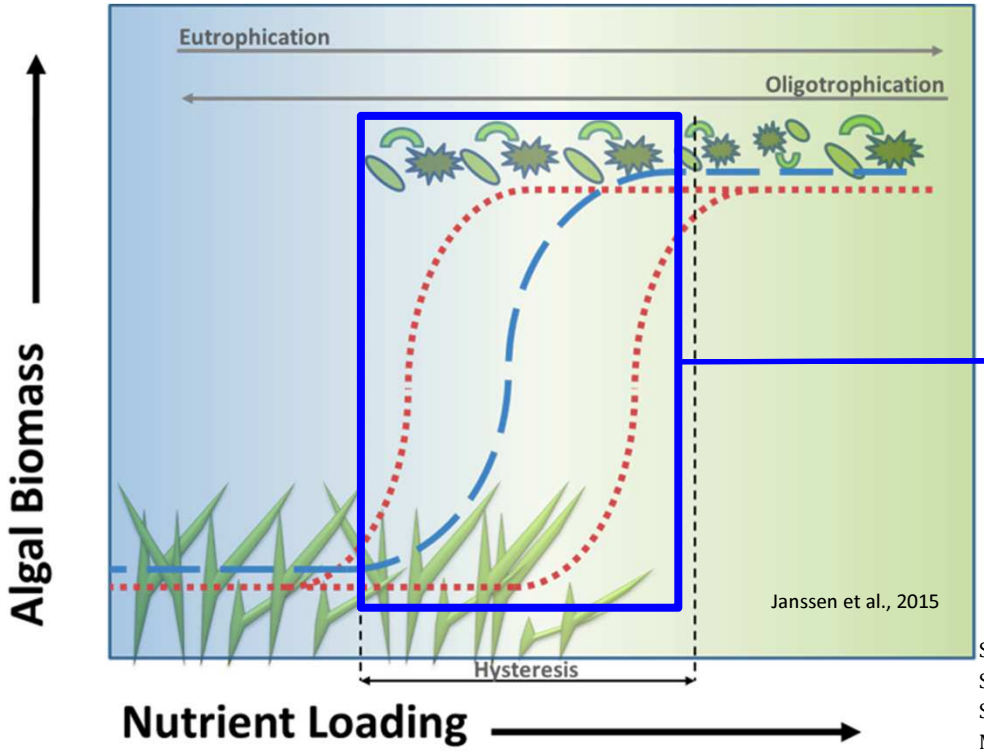


Using introduced species to control phytoplankton blooms





Stabilised by positive feedback mechanisms

Song S, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
Song Y, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
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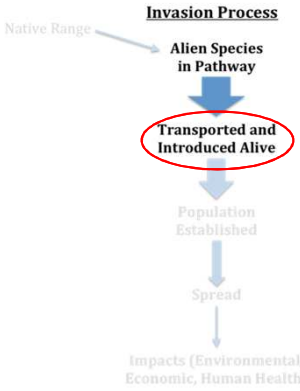

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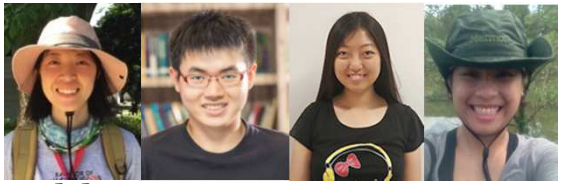

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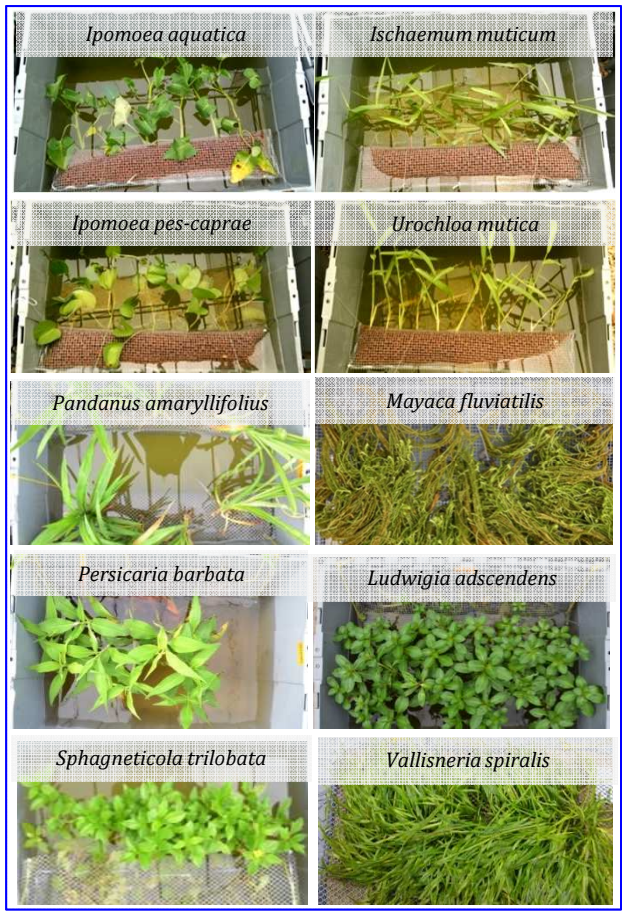

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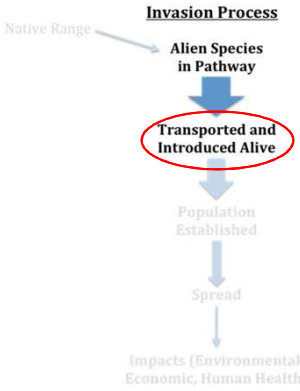

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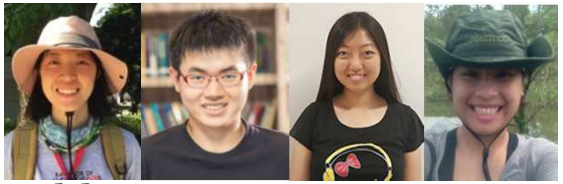
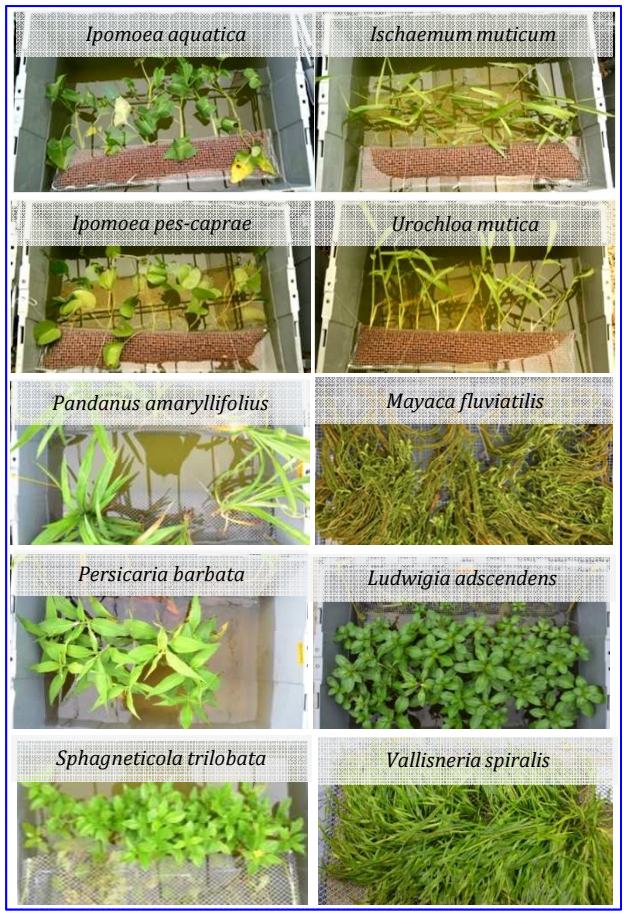
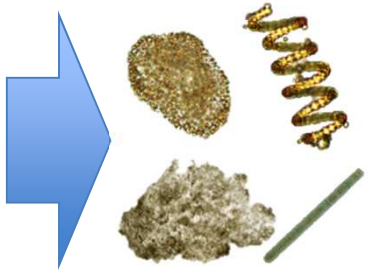


Using introduced species to control phytoplankton blooms





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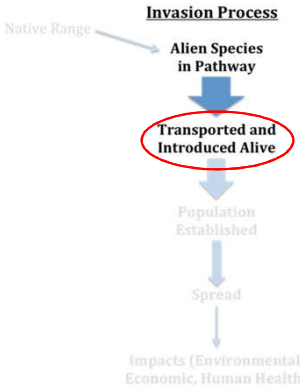

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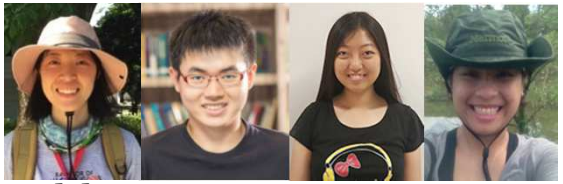
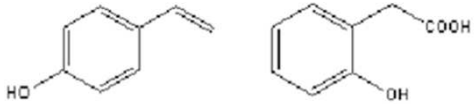


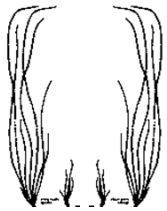
Using introduced species to control phytoplankton blooms

Reduce:

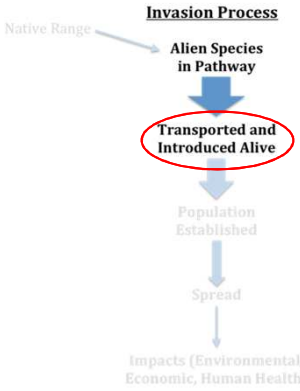
- Chlorophyll *a*
- Cyanobacterial dominance
- Total nitrogen



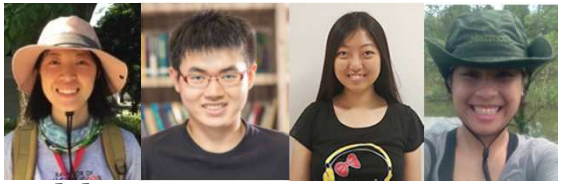
Allelochemicals



Song S, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
Song Y, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
Sim DZH, Mowe MAD, Mitrovic STan HTW, Yeo DCJ (in prep)
Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)



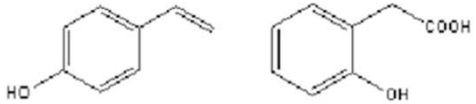
Introduced species



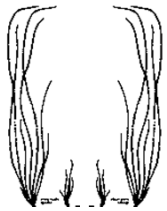
Using introduced species to control phytoplankton blooms

Reduce:

- Chlorophyll a
- Cyanobacterial dominance
- Total nitrogen



Allelochemicals



Song S, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
Song Y, Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)
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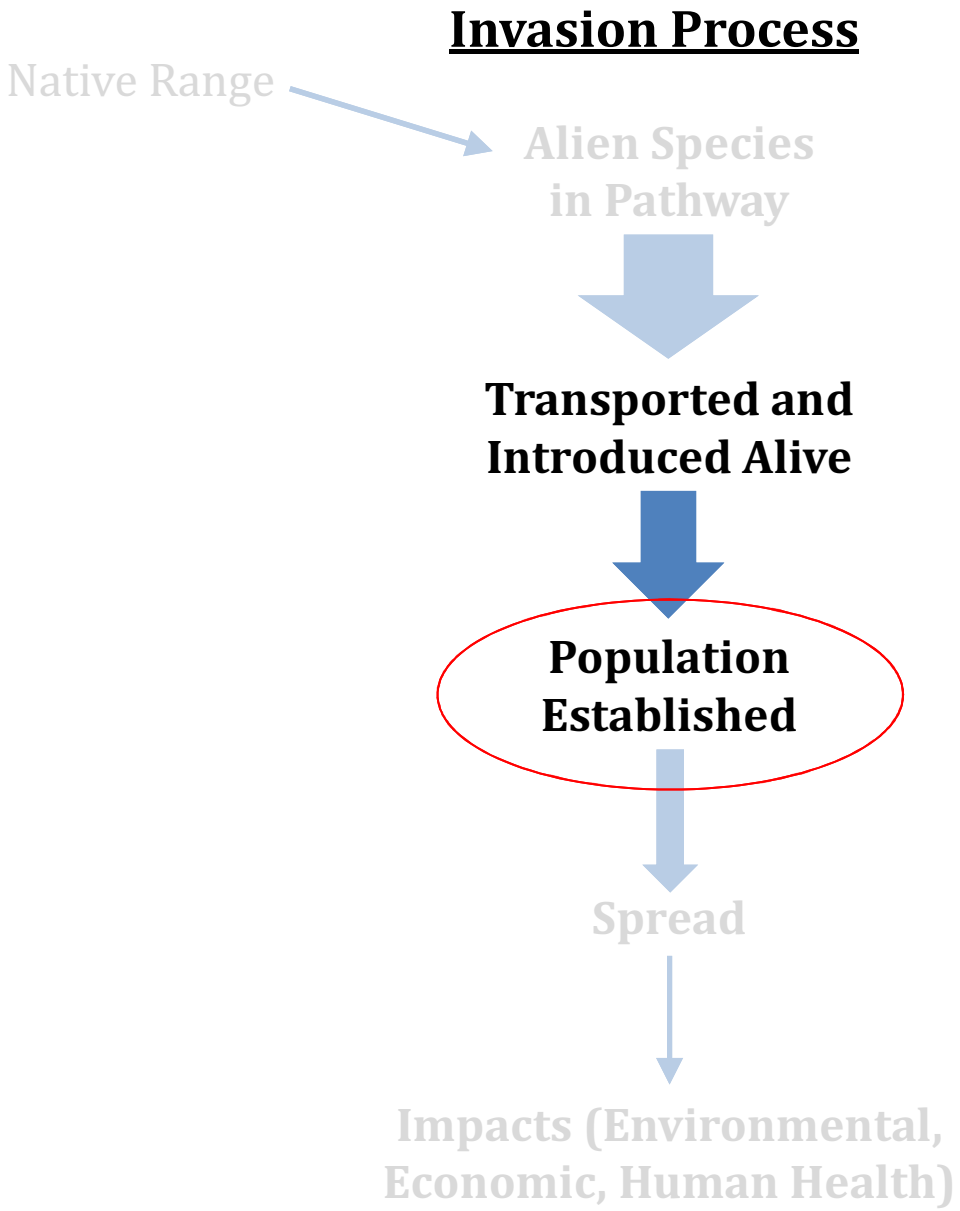
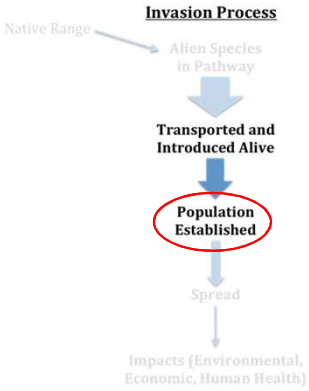
Mowe MAD, Mitrovic S, Tan HTW, Yeo DCJ (in prep)

Aquatic invasions

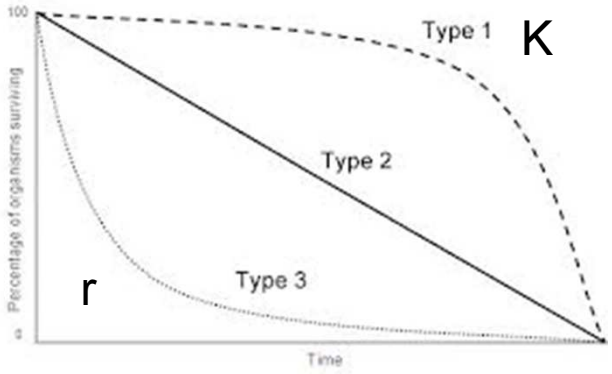


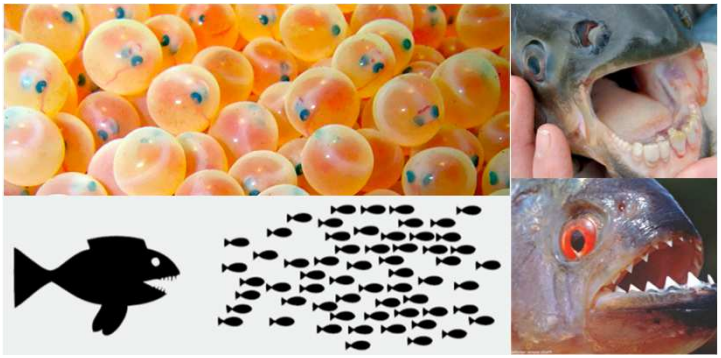


Established species

Which species will establish?

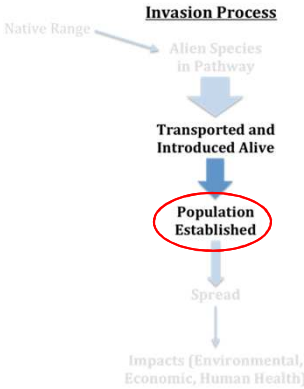
Based on species traits





Based on environmental conditions

Zeng Y, Chong KY, Grey EK, Lodge DM, Yeo DCJ (2015) *Biological Invasions*
Chan J, Zeng Y, Yeo DCJ (in prep)



Established species

Trait-based risk assessments

Important predictors:

Climate match
Invasion history
Fecundity
Trophic level

Human factors

All species

Range Clutch

Bait

Human Use

Range +Clutch

Barriers

Introduced

Clutch

Aquaculture

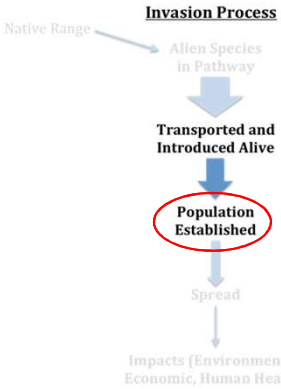
Human Use

Clutch

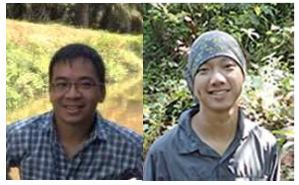
Barriers

Established

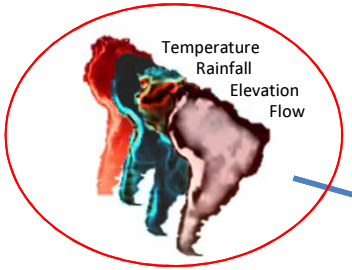
Zeng Y, Chong KY, Grey EK, Lodge DM, Yeo DCJ (2015) *Biological Invasions*

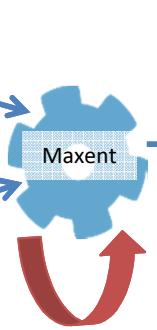


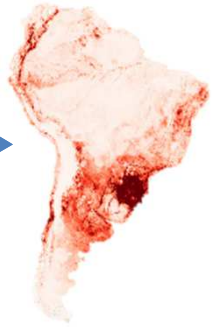
Established species

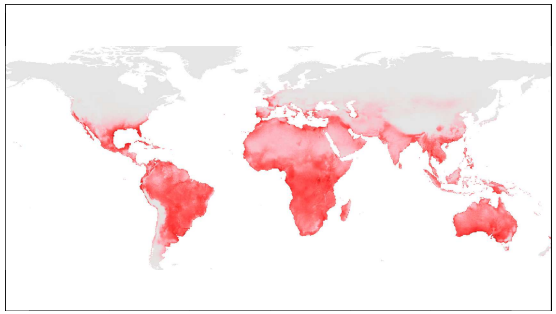


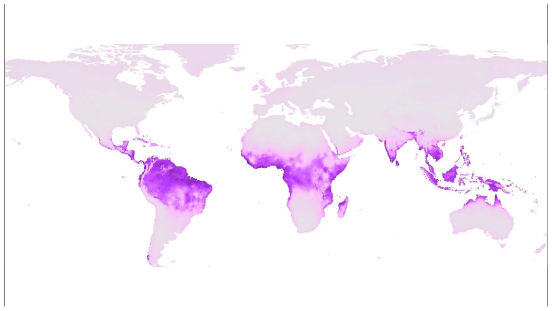
Species distribution modelling

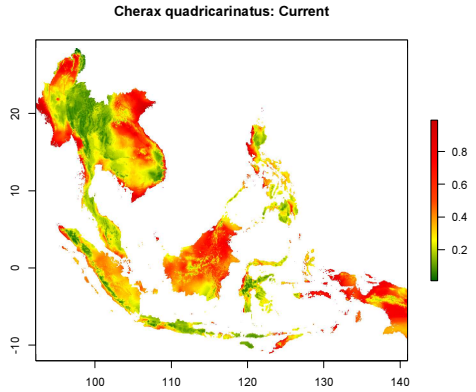


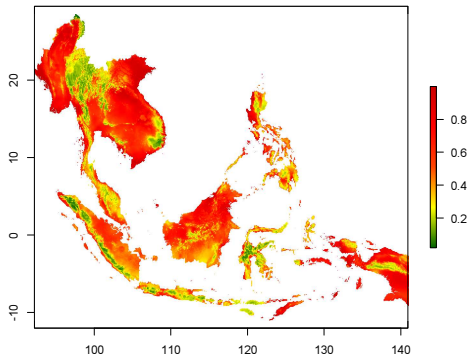




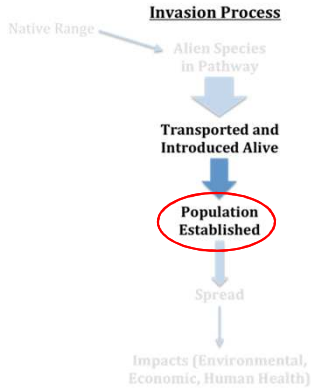








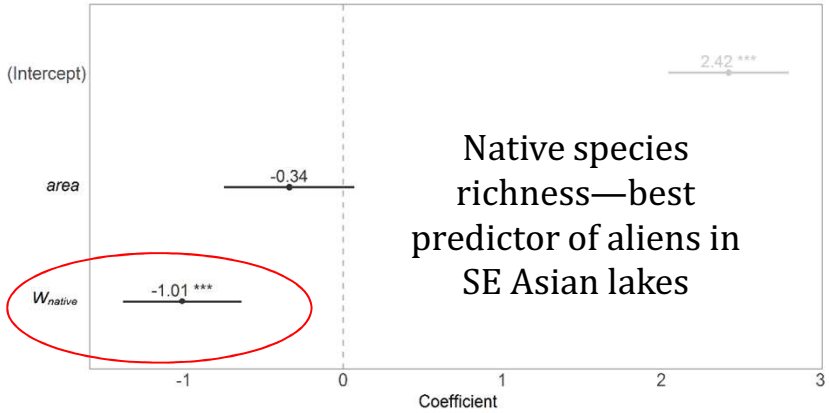
Zeng Y, Low BW, Yeo DCJ (2016) *Ecological Modelling*
Zeng Y, Yeo DCJ (in prep)
Low BW, Zeng Y, Yeo DCJ (in prep)



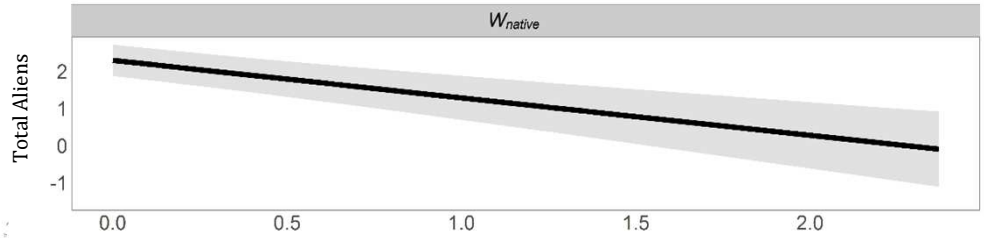
Established species

… contributing factors:

Native species richness

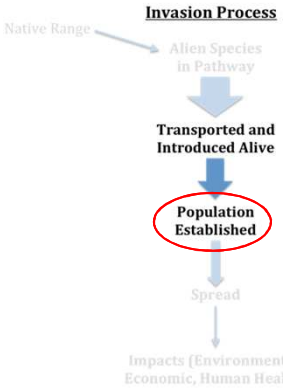


Native species richness—best predictor of aliens in SE Asian lakes



Biotic resistance?

Liew JH, Carrasco LR, Tan HH, Yeo DCJ (2016) *Biological Invasions*

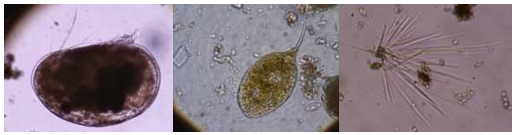


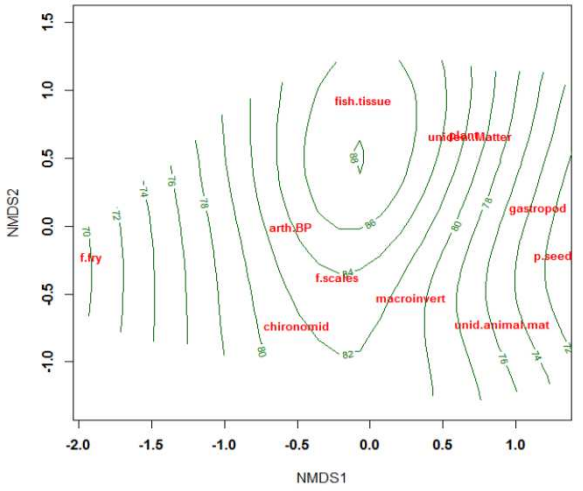
Established species

Ecology

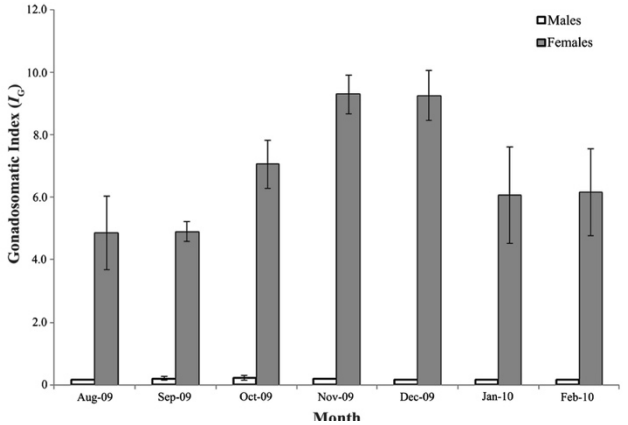
Feeding ecology

Gut content

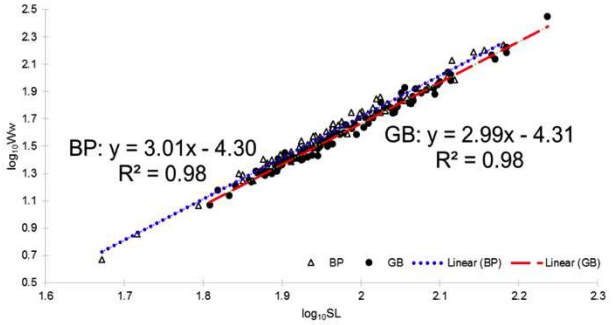




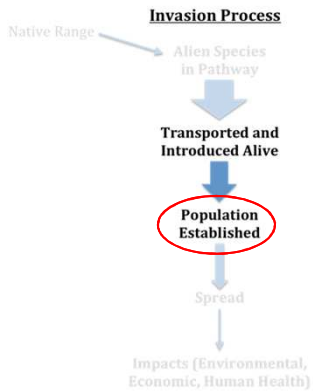
Reproductive ecology



Growth status



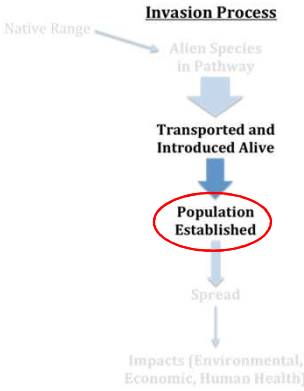
Liew JH, Tan HH, Yi Y, Yeo DCJ (2013) *Environmental Biology of Fishes*
Chen ML, Kwik JTB, Liew JH, Low BW, Tan HH, Yeo DCJ (in prep)
Low BW, Tan HH, Yeo DCJ (in prep)



Established species

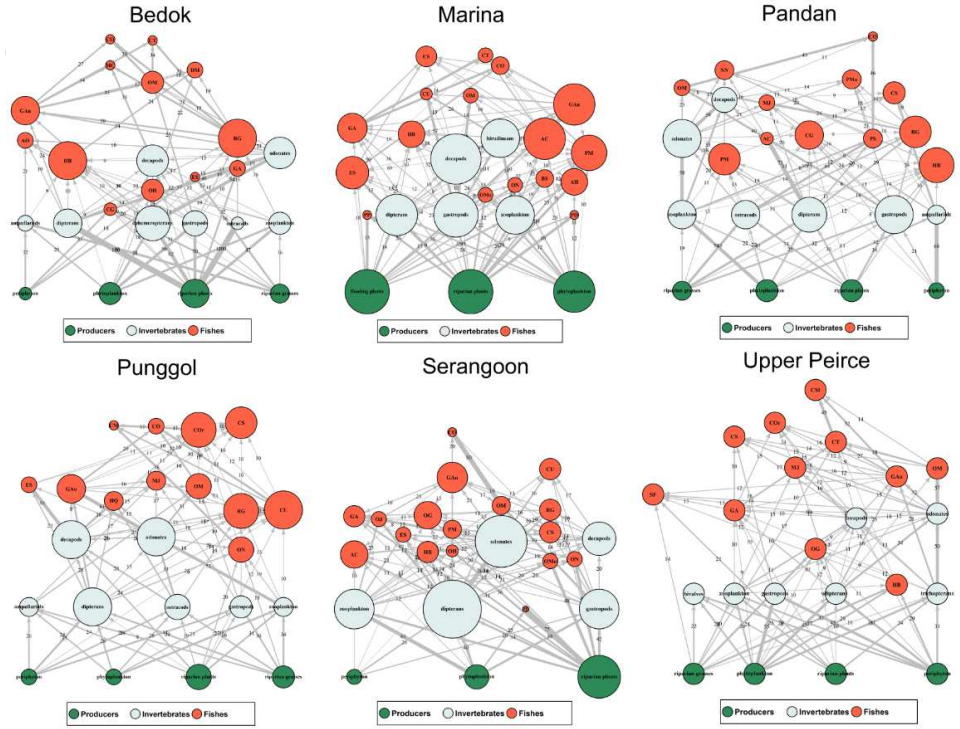
Forming novel foodwebs

- Total 47 species across six lakes
  - 8 native species
  - 39 non-native species
    - Mainly Afrotropical, Neotropical, and Oriental regions
    - Mostly dominated by Cichlidae

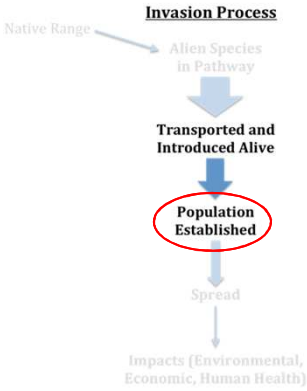


Established species

Forming novel foodwebs



Ng TH, Foon JK, Tan SK, Chan MKK, Yeo DCJ (2016) *BioInvasions Records*
Liew JH, Jardine TD, Tan HH, Yeo DCJ (in prep)
Liew JH, Kwik JTB, Lim RBH, Yeo DCJ (in prep)



Established species

Forming novel foodwebs

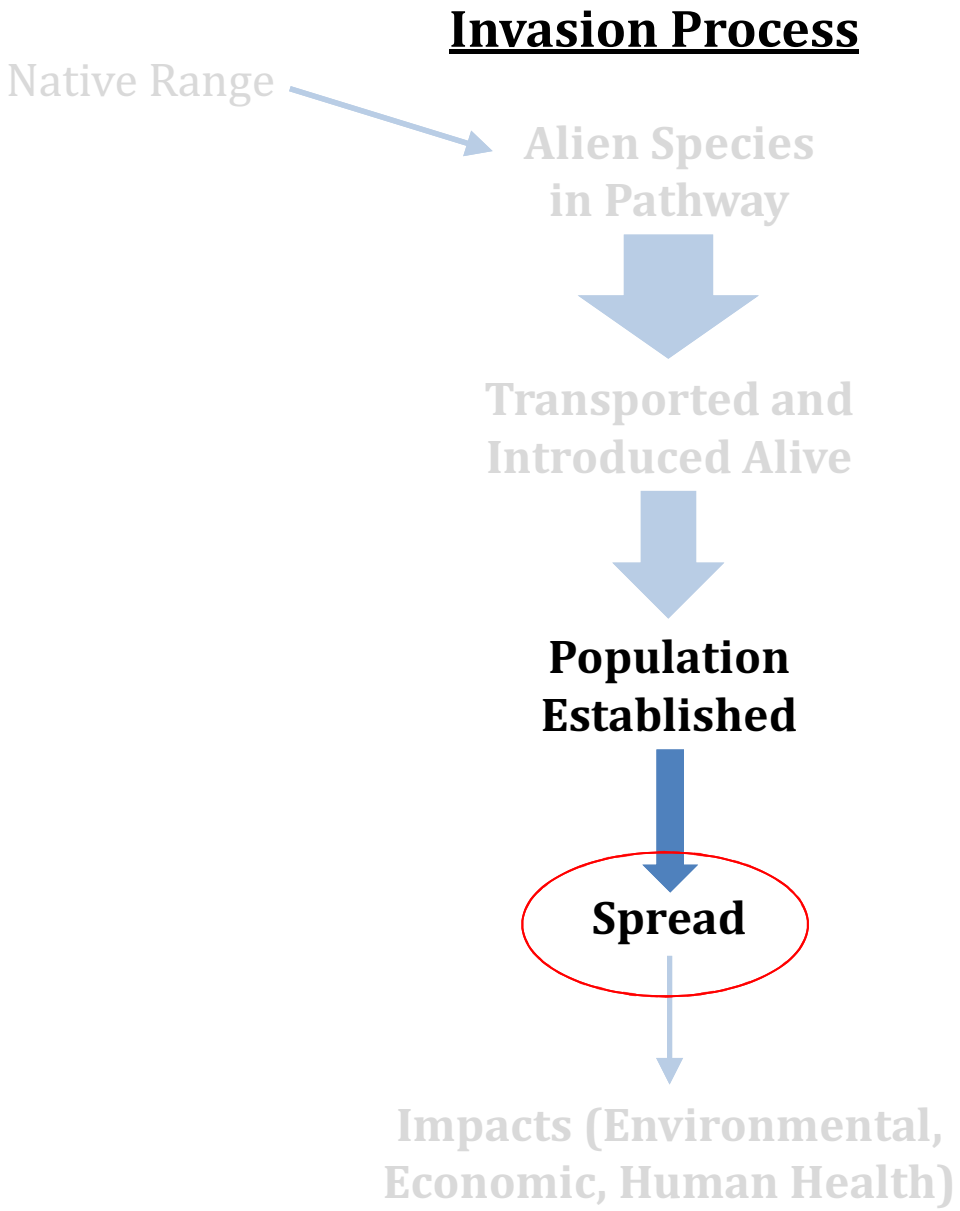
- Q: Are Singapore's artificial lake communities less complex than natural lakes?
- Different…
  - Richness
  - Total links

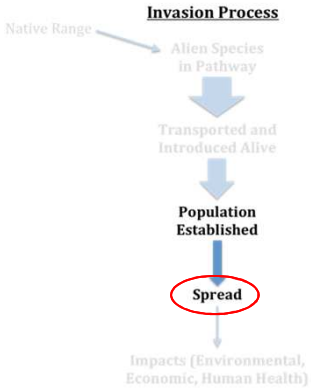
  …but comparable
  - Trophic levels
  - Connectance (complexity)

Artificial lakes	Taxa no.	Maximum trophic level	Total links	Connectance	Link Density
Bd	25	4.62	84	0.140	3.360
Ma	26	3.98	122	0.188	4.492
Pa	23	4.34	87	0.172	3.782
Pu	23	4.63	91	0.180	3.957
Sr	25	4.61	102	0.170	4.080
Up	22	4.54	92	0.199	4.182
Natural lakes	**Taxa no.**	**Maximum trophic level**	**Total links**	**Connectance**	**Link Density**
Laguna de Bay	57	4.210	370	0.116	6.491
Tonle Sap	99	4.070	901	0.093	9.101
Tasik Chini	64	4.100	401	0.100	6.266
Tasek Toba	42	3.933	232	0.135	5.524

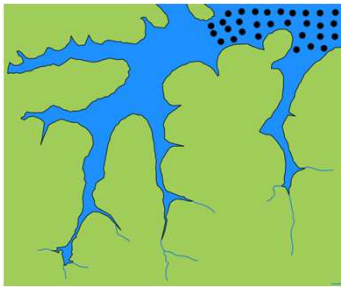
Ng TH, Foon JK, Tan SK, Chan MKK, Yeo DCJ (2016) *BioInvasions Records*
Liew JH, Jardine TD, Tan HH, Yeo DCJ (in prep)
Liew JH, Kwik JTB, Lim RBH, Yeo DCJ (in prep)

Aquatic invasions

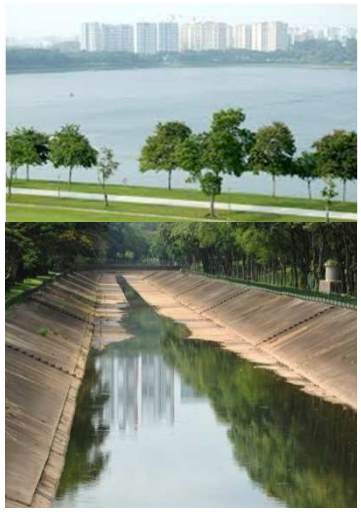




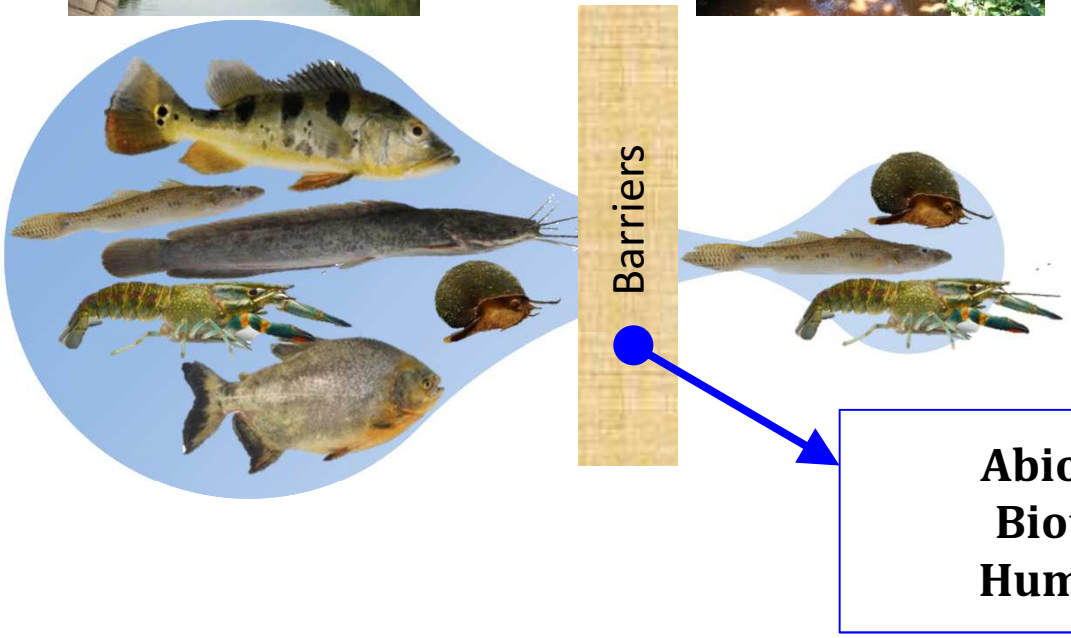
Spreading species

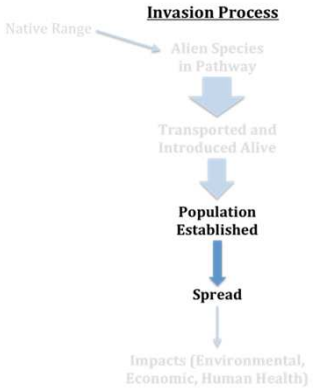


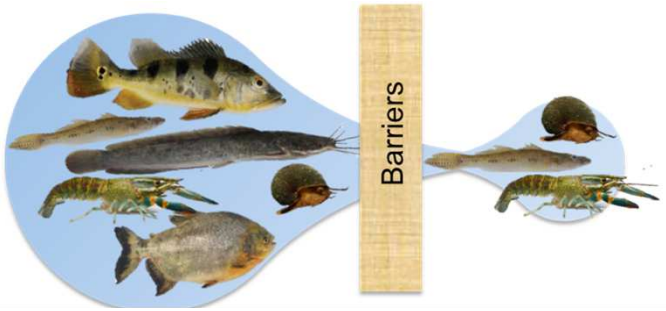
Disturbed urban habitats



Natural habitats





Spreading species

... contributing factors