Drivers and constraints of land cover land use change in Asian aquaculture hotspots

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The Hotel | 7777 Baltimore Avenue | College Park | Maryland 20740

(A) Background

- The farming of fish and shrimp has increased since 1990 by 700% to 64 million metric tons in 2020 with a market value of $138 billion;
- 80% of global aquaculture production takes place in Asia, in both coastal brackish and inland freshwater areas;
- Asian aquaculture is generally assumed to be small scale, but the size and tenure of aquaculture farms is poorly documented, and the factors that drive and mediate aquaculture change are understudied;
- there are scarce publicly available data on the boundaries of aquaculture "ponds", which is the fundamental unit of aquaculture practice.

Aquacultural land cover land use change (LCLUC)

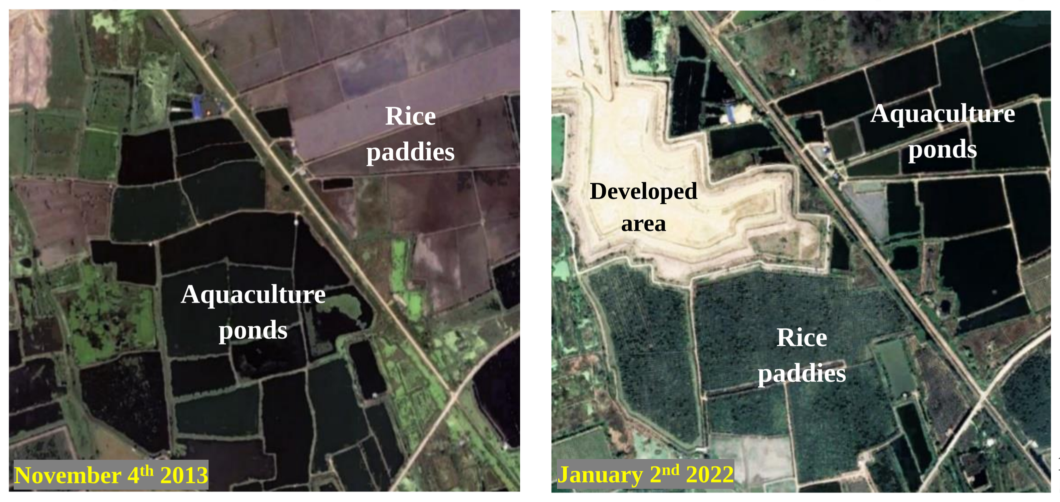


Fig. 1. Google-Earth images showing examples of aquaculture-associated LCLUC in Nong Ping, Ratchaburi, Thailand.

Aquacultural intensification

Fig. 2. Google-Earth images showing examples of aquacultural intensification in Jamalnagar, Satkhira, Bangladesh.

(B) Asian aquaculture hotspots

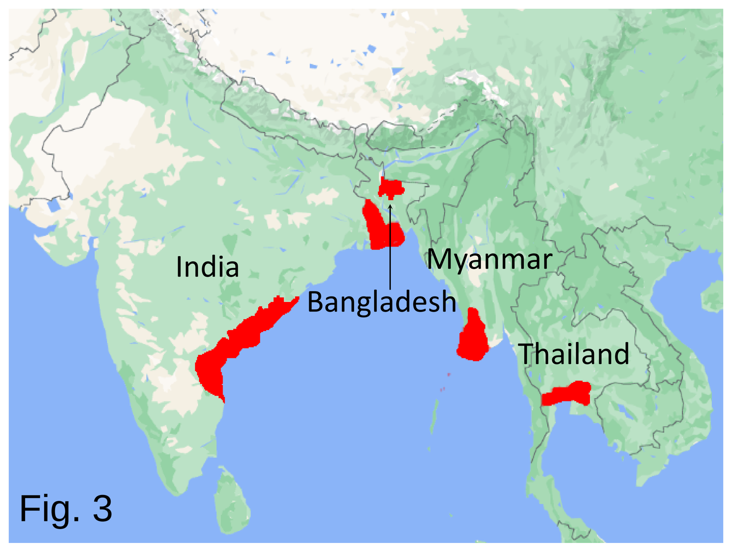


Fig. 3

Table 1. Characteristics of the aquaculture hotspot study areas and survey data status

Hotspot country (study area)	Smallholder farms	Industrial-scale farms	Technology level	Land use regulation	Urbanization	Survey data	Collaborators
Myanmar (Ayeyarwady Delta)	Many	Many	Low-mid	High	Low	Collected 2016	N/A
Bangladesh (southwest and north)	Many	Few	Low-mid	Low	Mid	Collected 2013 and 2021	N/A
Thailand (Central Plains)	Many	Some	Mid-high	Some	High	Collected 2012 & Proposed	Napasintuwong, Kasetsart Univ.
India (Andhra Pradesh)	Many	Many	Mid-high	High	Low	Proposed	A.B.C. Mohan, Seafood Solutions

(C) Research questions and hypotheses

#1: What are the primary patterns of aquaculture-associated LCLUC behind expansion and contraction? Hypotheses:

- aquaculture expansion occurred primarily through conversions from agricultural land and freshwater wetland to ponds;
- aquaculture-area contraction is driven primarily by urbanization.

#2: What proximate factors drive and constrain aquaculture expansion and contraction? Hypotheses:

- aquaculture expansion or contraction in each hotspot is driven/constrained by a confluence of
  - changes in relative factor prices (e.g., land, labor),
  - changes in demand and market prices for seafood such as experienced during the COVID-19 pandemic,
  - catastrophic aquatic disease events,
  - recurrent climatic shocks such as severe flood events,
  - application of policies that favor aquaculture development, agricultural land use or urban development.

#3: How is the spatial organization of aquaculture farms changing over time in response to proximate drivers? Hypotheses:

- average aquaculture farm sizes are increasing in some hotspot study areas but are decreasing in others due to changes in factor prices, profitability, species specific disease, management strategies, and consumer species preference that require different capital investment and different forms of production;
- where aquaculture is becoming more capital intensive, spatial intensification of aquaculture ponds with smaller pond sizes is expected;
- technology development may also push intensification of intensive aquaculture (smaller and dense ponds).

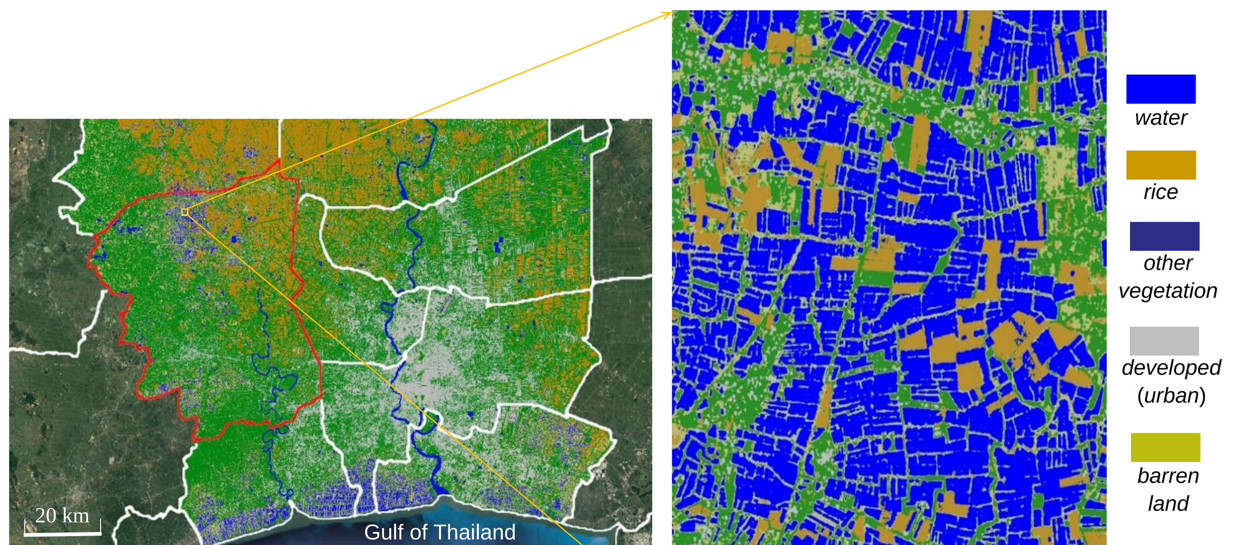
#4: How can macro-scale variation in patterns of aquaculture land use and spatial organization of farms observed across the four hotspots be accounted for? Hypotheses:

- aquaculture land use change across the four hotspots follows an 'inverted U' shaped curve: from relatively slow aquaculture growth at lower levels of economic development and global market integration (e.g., Myanmar), through higher and more rapid horizontal expansion concurrent with intensification at higher levels of economic growth and openness (e.g., India and Bangladesh), followed by intensification and spatial concentration at the highest levels of economic development and sectoral maturity (e.g., Thailand).

(D) Research tasks

#1: Aquaculture pond extraction and validation for years 2015-2024 in hotspot study areas from Sentinel-2 and commercial high-resolution satellite images
#2: Generation of maps to characterize changes in aquaculture-associated LCLUC and aquacultural pond sizes for 2015-2024
#3: Collection and compilation of survey data on hypothesized proximate drivers and constraints of aquacultural land use, spatial organization, and aquacultural change
#4: Analysis to address research questions and hypotheses

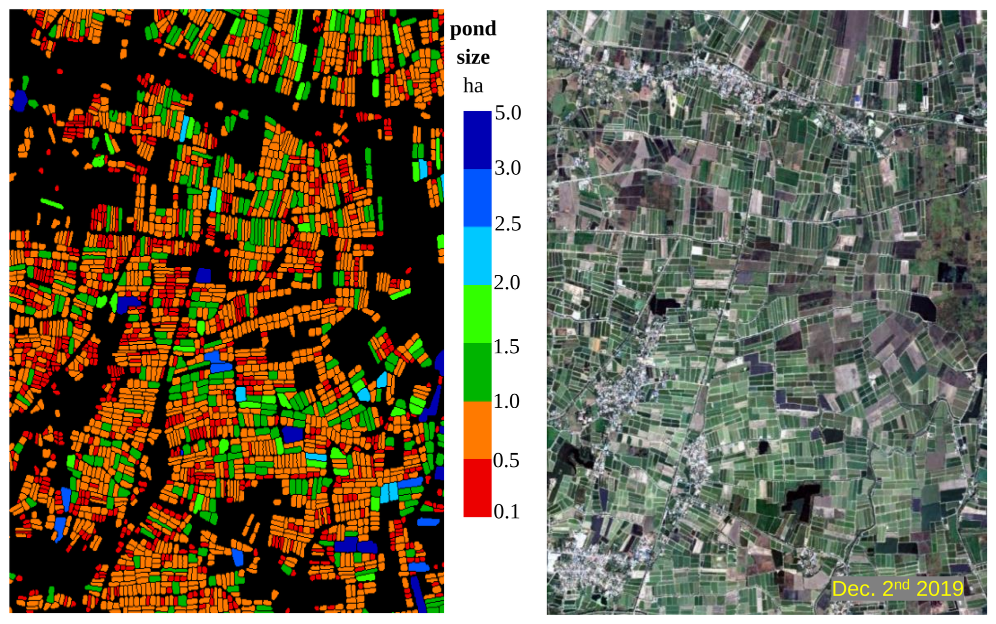
(E) Satellite-based land cover classification and aquaculture pond extraction (proof of concept)



10m year 2019 land cover map, central Thailand
white = province boundaries,
red = Nakhon Pathom Province

6 × 7 km subset in Sa Phatthana subdistrict, Nakhon Pathom Province. Surveys indicated 80-90% of the rice paddies in the subdistrict had been converted to shrimp ponds since 1990s.

Fig. 4. Example of preliminary Sentinel-1 based land cover classification



Aquaculture ponds colored by pond size

Google-Earth image for reference

Fig. 5. Example aquaculture pond extraction from 2019 seasonal Sentinel-2 10m images (Yan et al. 2022).

(F) Multi-decade field/pond extraction in smallholder areas

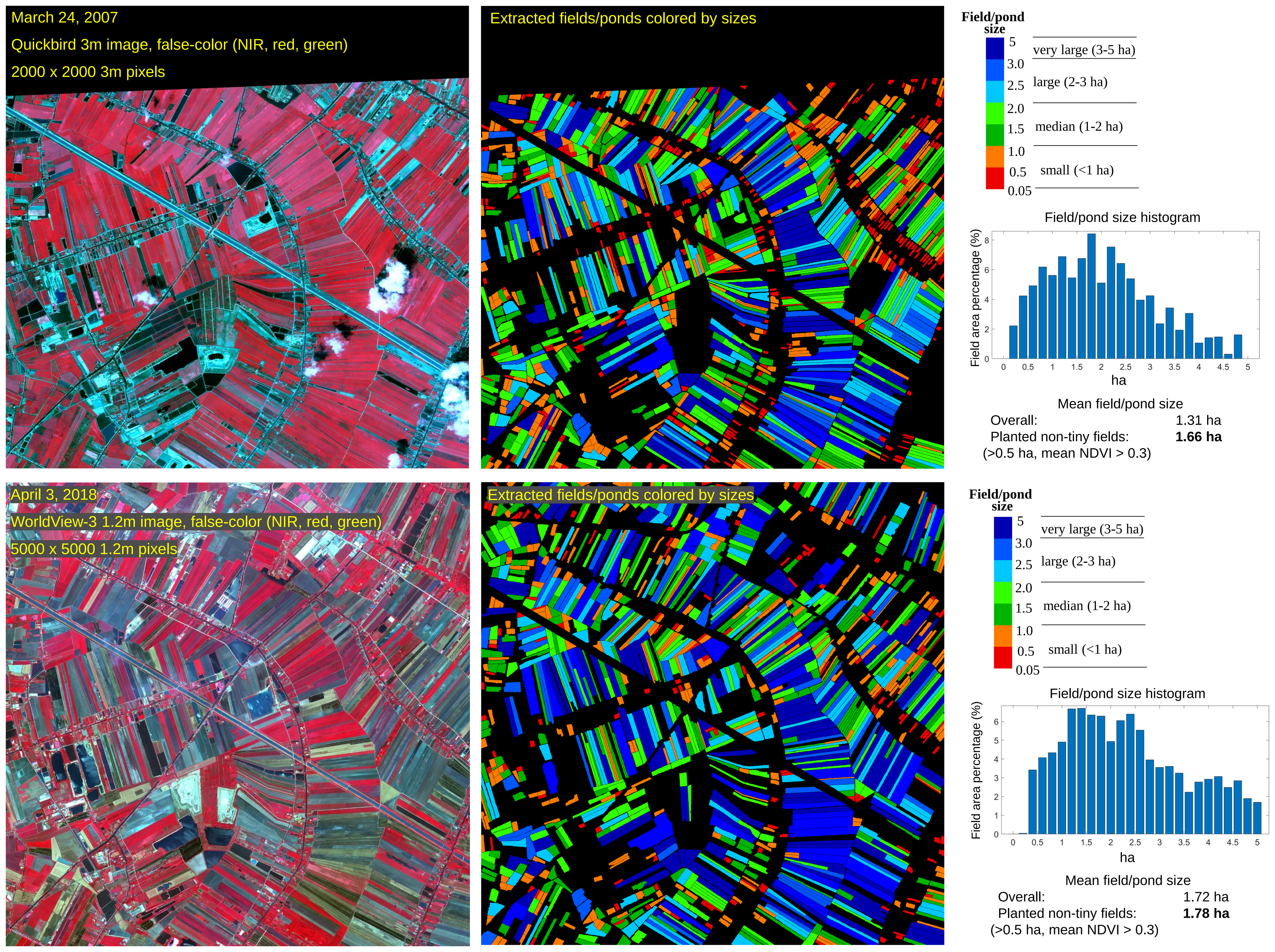
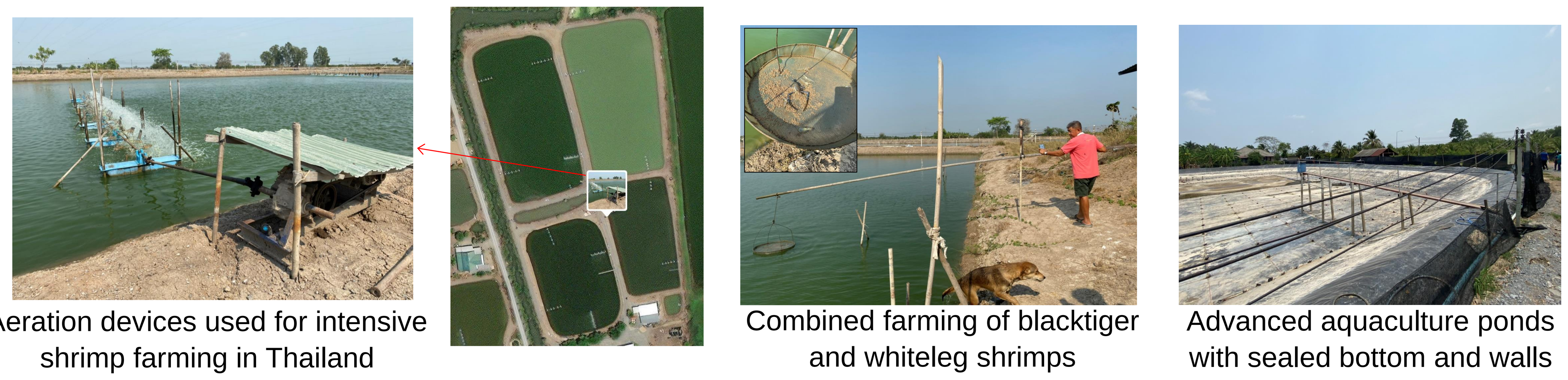


Fig. 6. Examples of field/pond extraction from commercial satellite images in Bua Pak Tha subdistrict, Nakhon Pathom Province, central Thailand. Commercial satellite data provided by NASA CSDA program.

(G) Recent aquaculture survey pre-test

- Draft aquaculture survey questionnaires with remote-sensing-related components were pre-tested in Thailand and India in April and May 2023.
- Surveys of 400 aquaculture farms in each of the Thailand and Indian study areas will be undertaken this Summer.

Interviews with aquaculture farmers by the MSU team and collaborators at Kasetsart University



Aeration devices used for intensive shrimp farming in Thailand

Combined farming of blacktiger and whiteleg shrimps

Advanced aquaculture ponds with sealed bottom and walls

Fig. 7. Pre-test of aquaculture questionnaires undertaken in April 2023 in fish and shrimp farms in Sam Phran and Bang Len subdistricts, Nakhon Pathom Province, Thailand; and photos of different aquacultural farms.

(H) Estimation of annual aquaculture farming cycles using Sentinel-1 SAR time series

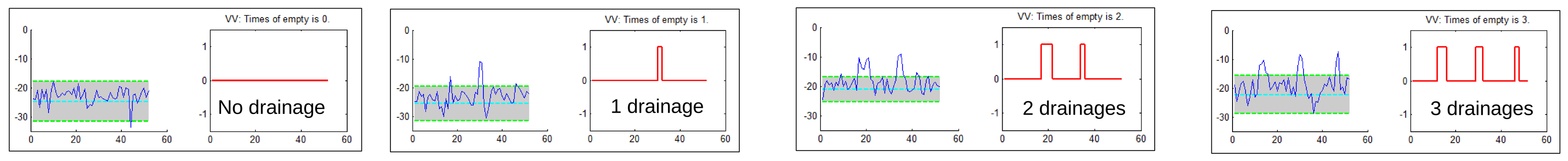
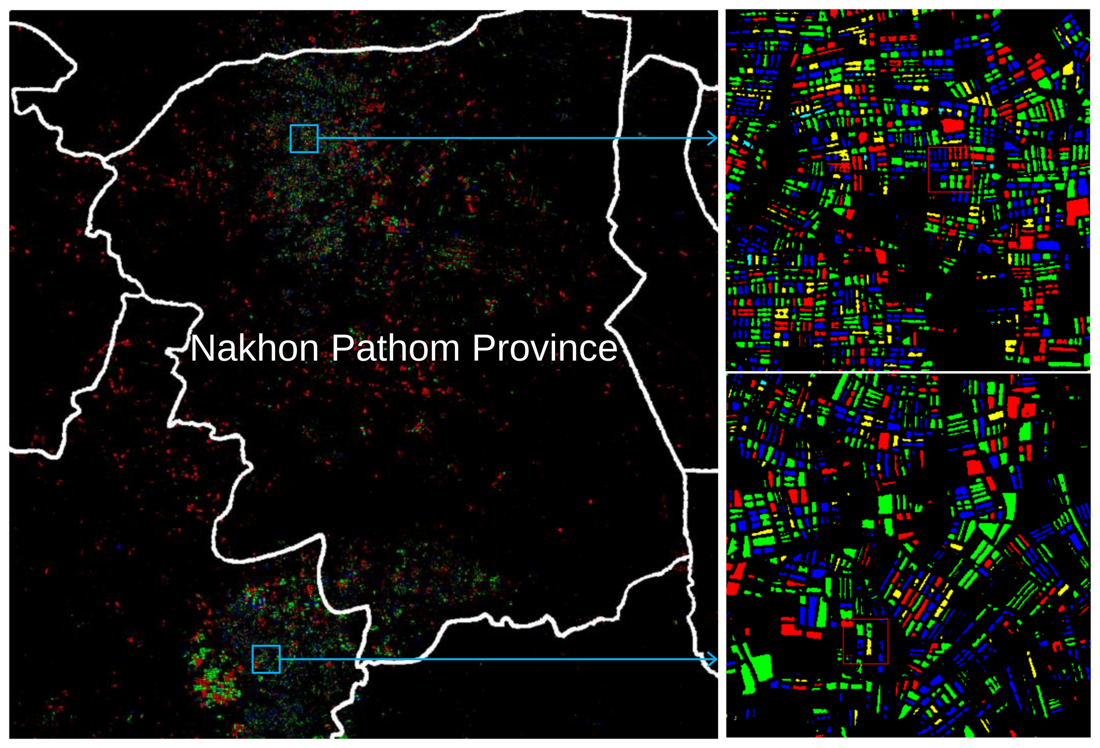


Fig. 8. Example Sentinel-1 SAR time series detection of pond drainage and filling over 4 aquaculture ponds



- Estimate number of aquaculture farming cycles for individual ponds based on pond extraction (Fig. 5) and pond drainage detection (Fig. 8).
- This will provide useful information on aquaculture production, income, water usage, and disposals of effluent and waste sewage.
- Survey pre-tests suggest pond drainage periods are typically 10-20 days; this is also apparent in the Sentinel-1 time series (Fig. 8).

# of drainages
Red: 0
Green: 1 time
Blue: 2 times
Yellow: 3 times

Fig. 9. Annual map of number of times ponds-drained-per-year based on Fig. 8 approach in central Thailand.