Preliminary results on drivers and constraints of land cover land use change in Asian aquaculture hotspots

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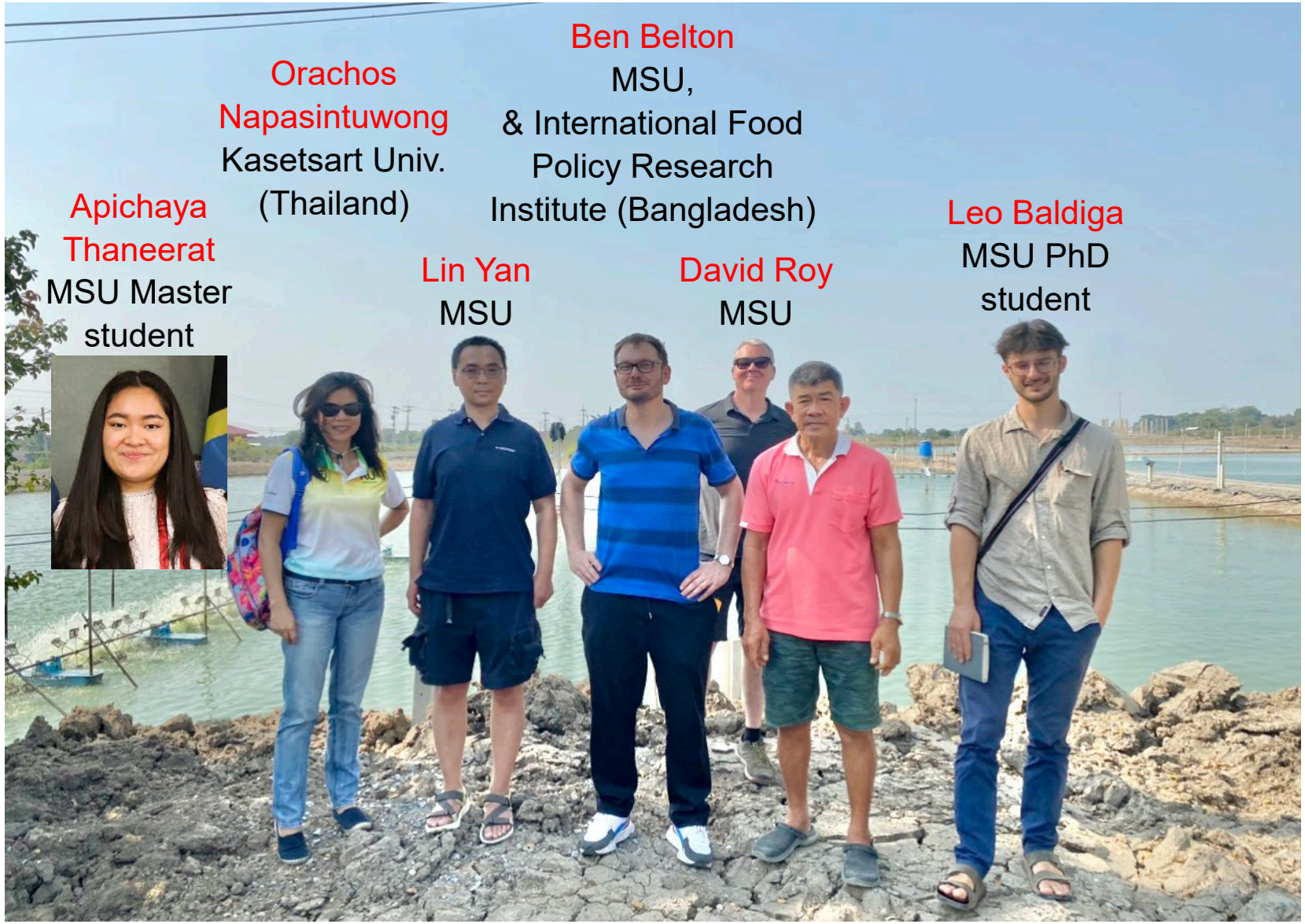
NASA LCLUC Science Team meeting, Gaithersburg, MD, April 2-4, 2024

Team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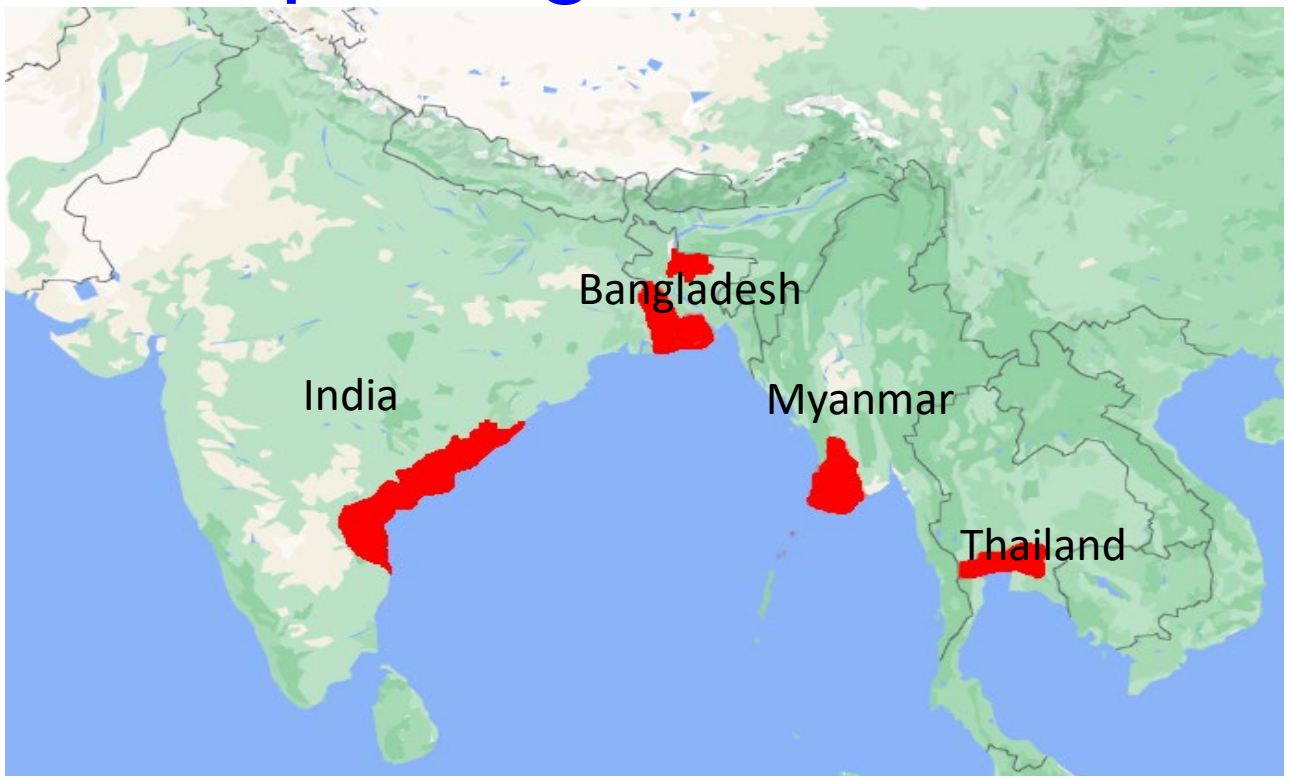
Background

- Global aquaculture production (fish and shrimp) has increased rapidly
  - seven-fold increase from 1990 to 2020
  - global $138 billion market value (2020)
- >80% of aquaculture production is in Asia
  - significant aquaculture expansion
  - pre-1980s predominantly in coastal and near-coastal brackish-water areas
  - late-1980s onwards started to move to inland freshwater areas
  - causing issues: mangrove loss, natural habitat destruction, water pollution, soil salinization,…
- Asian aquaculture is generally small-scale
  - factors driving and constraining aquaculture-associated LCLUC are understudied
  - aquaculture-associated LCLUC is not unidirectional (farmers switch between aquaculture and crop farming)
  - no publicly-available aquaculture pond boundary data

Aquaculture changes spatially & temporally (2017-2023)

Nakhon Pathom, Thailand

Aquaculture hotspot regions considered in this project



Hotspot region

Hotspot country (region)	Smallholder farms	Industrial-scale farms	Technology level	Land use regulation	Survey data
Myanmar (Ayeyarwady Delta)	Many	Many	Low-mid	High	Collected 2016
Bangladesh (southwest and north)	Many	Few	Low-mid	Low	Collected 2013 and 2021
India (Andhra Pradesh)	Many	Many	Mid-high	High	Proposed
Thailand (Central Plains)	Many	Some	Mid-high	Some	Proposed

Research objectives

- #1 Generate maps to characterize aquaculture pond sizes and aquaculture-associated LCLUC 2015-2024
  - pond extraction using Sentinel-2 & commercial high-res. imagery
  - validation using GoogleEarth and commercial high-res. imagery

- #2 Conduct surveys to collect information on hypothesized drivers and constraints of aquacultural LCLCU

- #3 Address 4 hypotheses

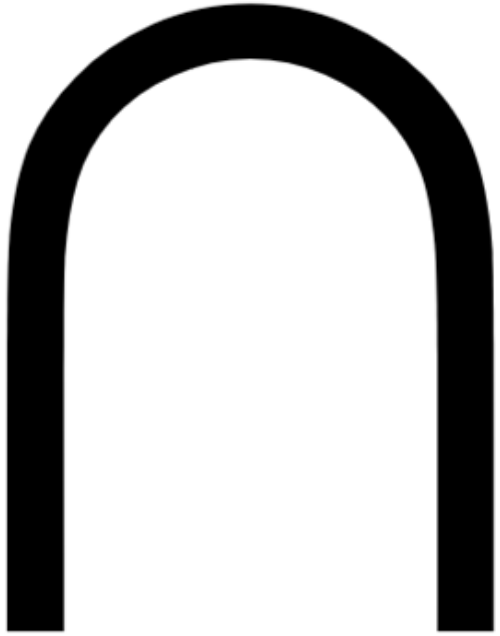
Research hypotheses

- Hypothesis 1:

  aquaculture development - ‘inverted U’ trajectory

Rapid expansion at higher levels of economic growth and openness

Examples: India and Bangladesh



Slow growth at low-levels economic development and global market integration

Example: Myanmar

Intensification and spatial concentration at the highest levels of economic development and sectoral maturity

Example: Thailand

Research hypotheses

- Hypothesis 2

  primary patterns of aquacultural change:

  – expansion: cropland -> ponds, wetland -> ponds

  – contraction: ponds -> urban areas

- Hypothesis 3

  aquaculture expansion/contraction driven and constrained by:

  – relative factor prices (e.g., land, labor)

  – changes in the demand and market prices

  – aquatic disease outbreaks

  – recurrent climatic shocks such as severe flood events

  – policies favoring aquaculture development, agricultural land, or urban development

Research hypotheses

- Hypothesis 4

  aquaculture's spatial organization changes over time

  – ponds becoming smaller and more spatially-concentrated
    - due to intensive farming

  – aquaculture farm size overall increases, but may also decrease
    - 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)

Overview of Current Progress (end of year 1)

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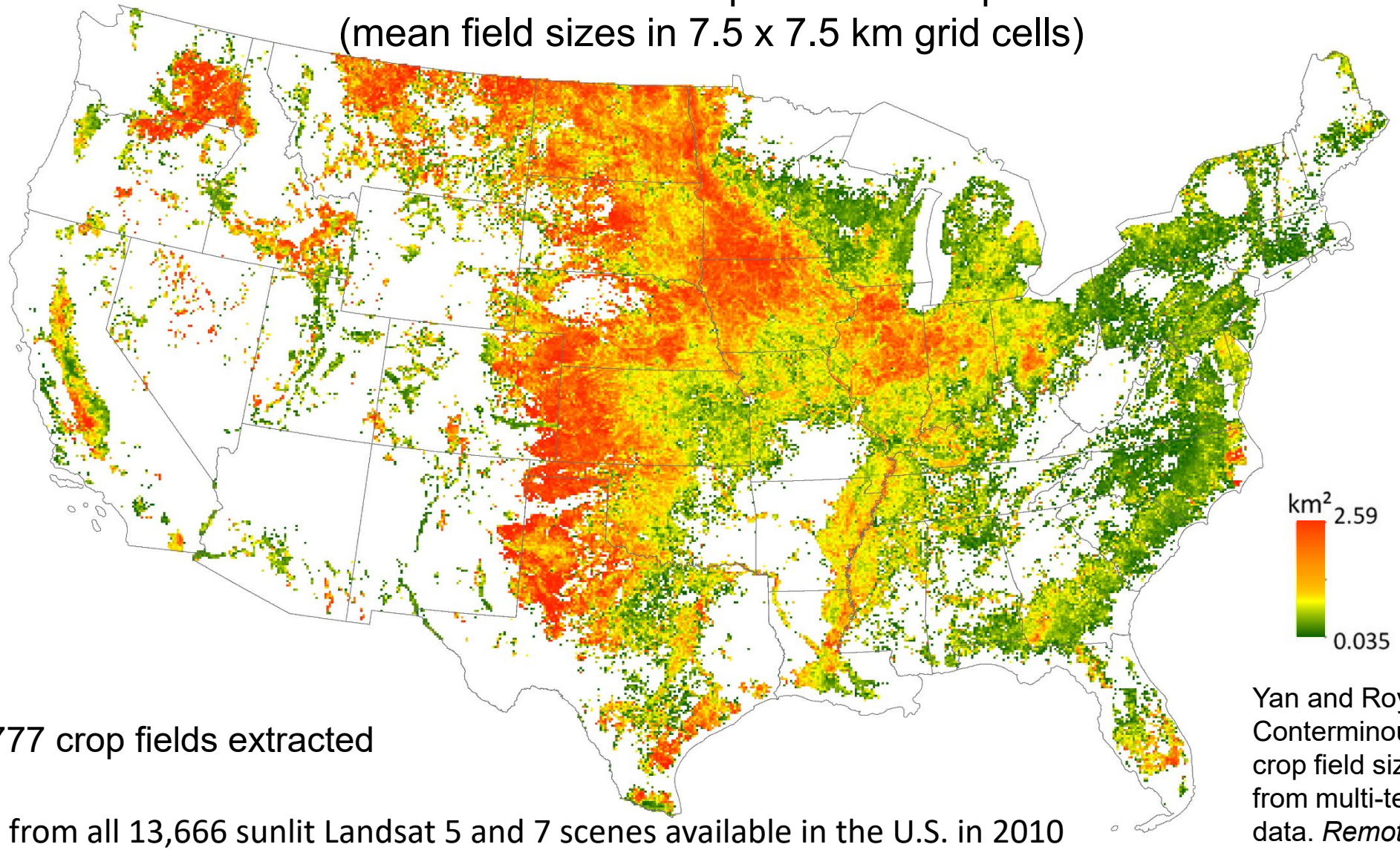
Algorithm based on previous crop field extraction from Landsat

2010 CONUS crop field size map
(mean field sizes in 7.5 x 7.5 km grid cells)



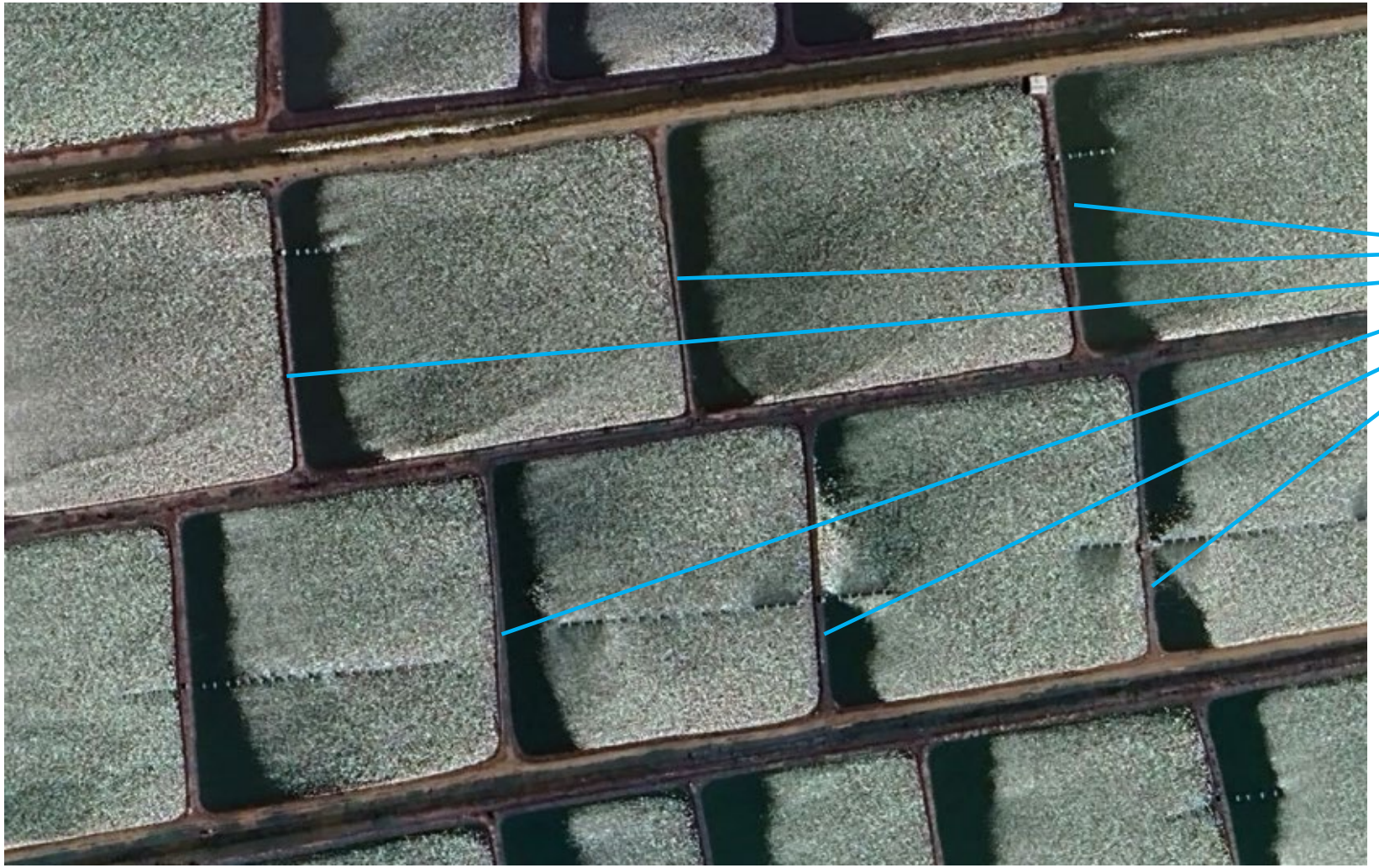
4,182,777 crop fields extracted

Derived from all 13,666 sunlit Landsat 5 and 7 scenes available in the U.S. in 2010

Yan and Roy (2016). Conterminous United States crop field size quantification from multi-temporal Landsat data. *Remote Sensing of Environment*, 172, 67-86.

Algorithm refinement for detection of faint pond edges

Example Google Earth image

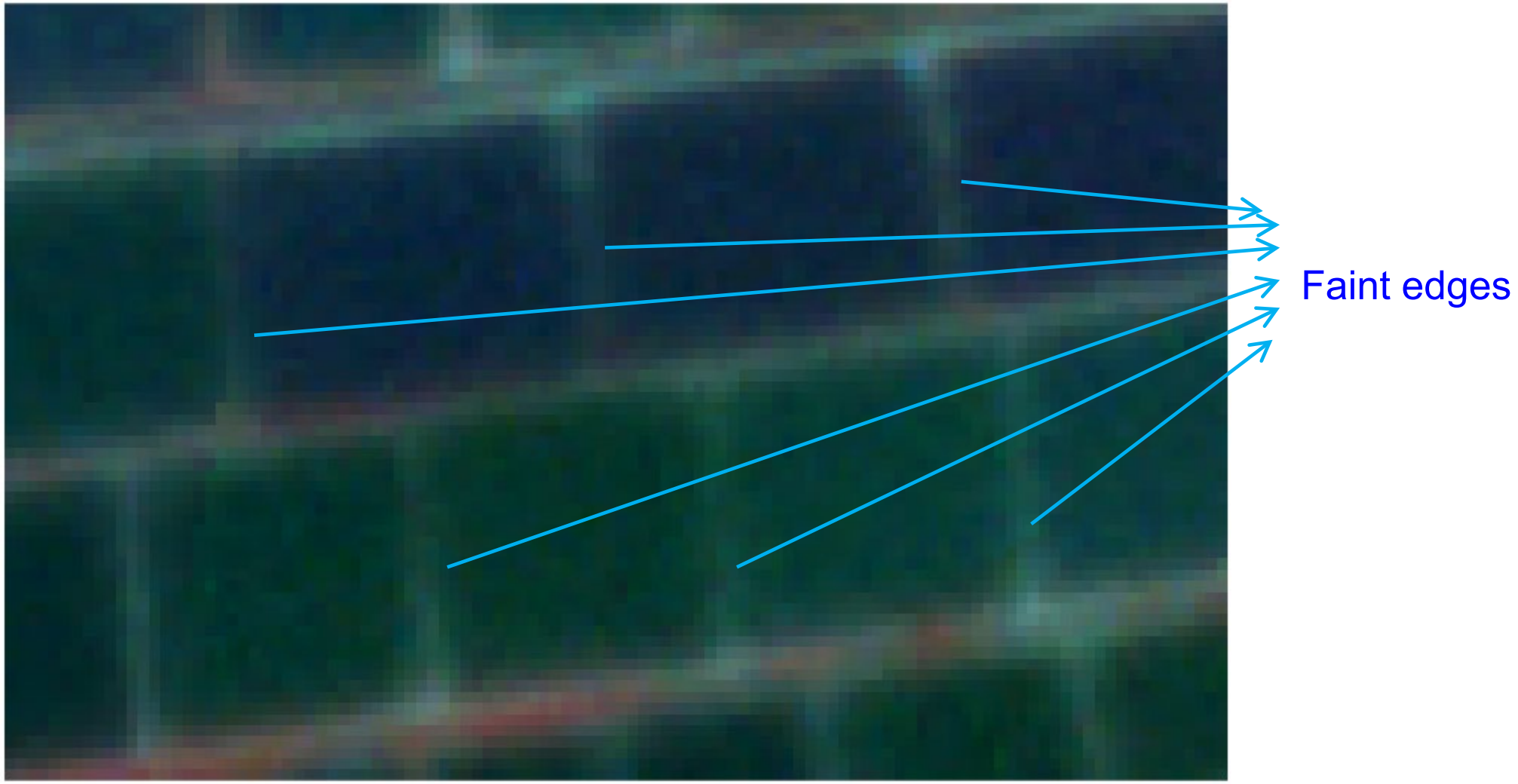


Nakhon Pathom Province, Central Thailand

However, spatially-complete and up-to-date very-high resolution (1-2 m) commercial satellite images are unavailable

Algorithm refinement for detection of faint pond edges

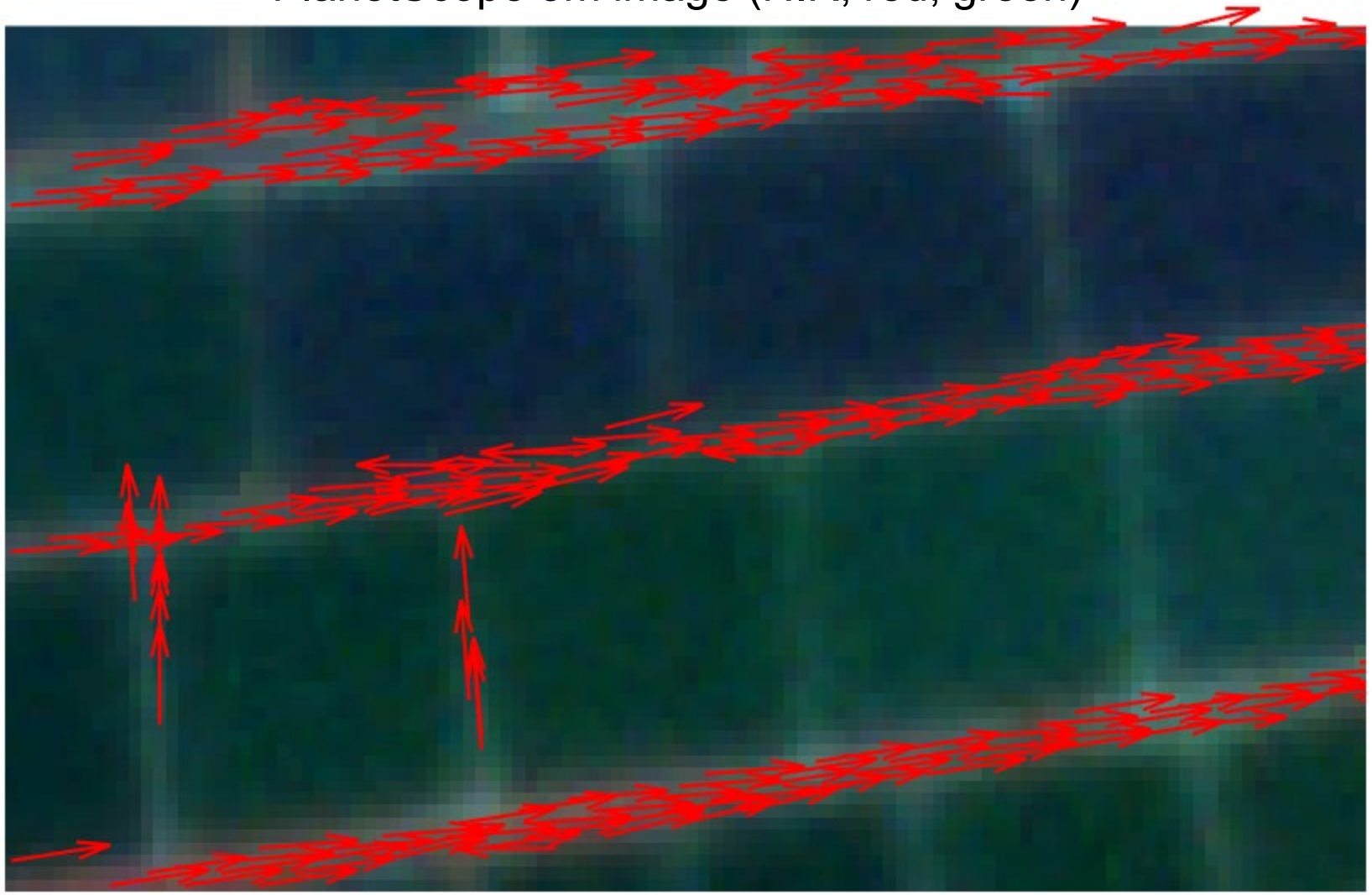
PlanetScope 3m image (NIR, red, green)



3m resolution, frequent global coverage, and free (for research)
but may have degraded image quality due to the smallset sensors

Algorithm refinement for detection of faint pond edges

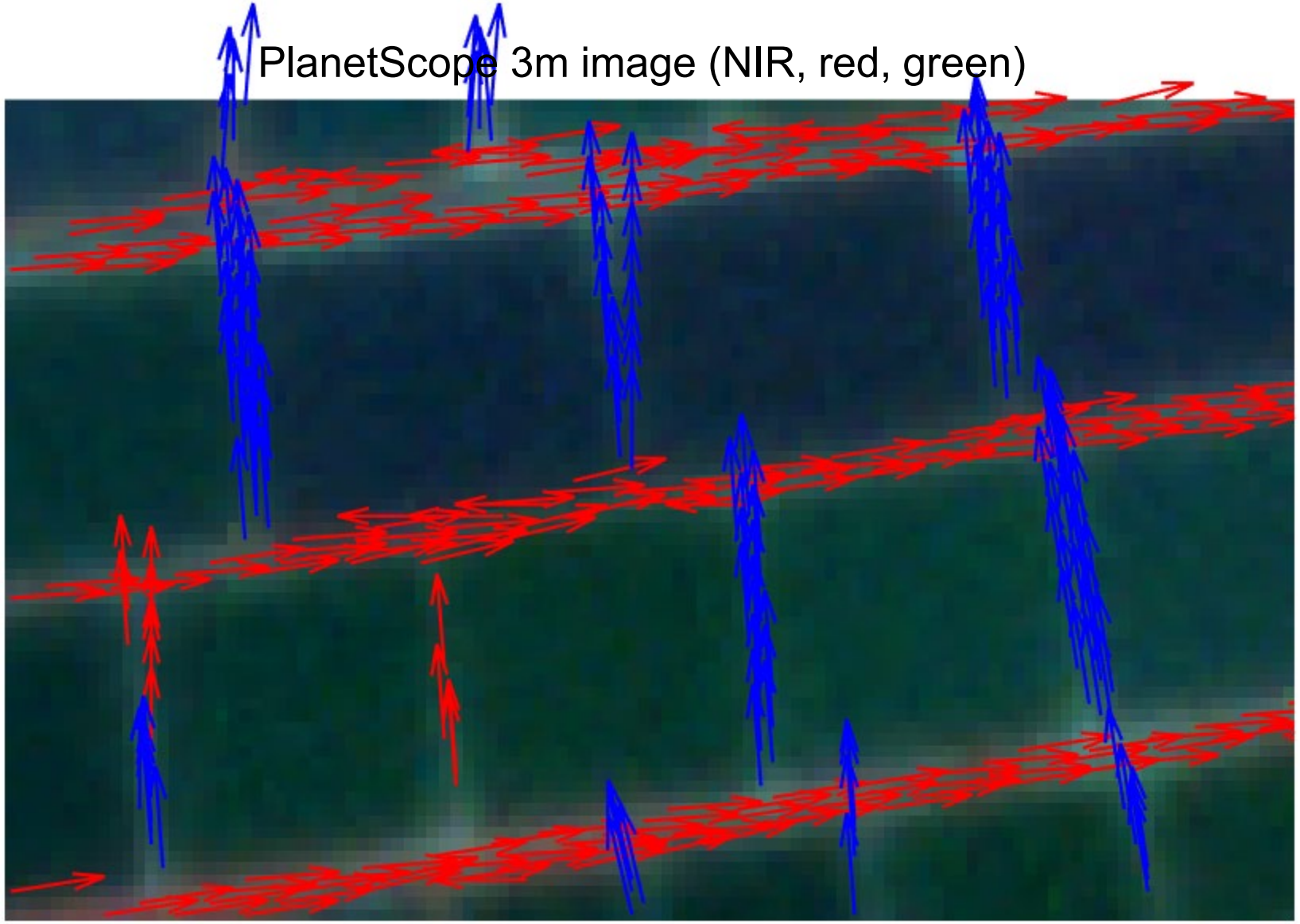
PlanetScope 3m image (NIR, red, green)

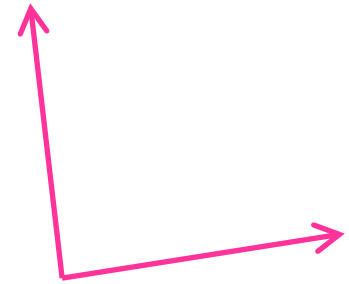


Derive major edge orientations

Detect obvious edges (and their orientations)

Algorithm refinement for detection of faint pond edges





Derive major edge orientations

Detect new edges

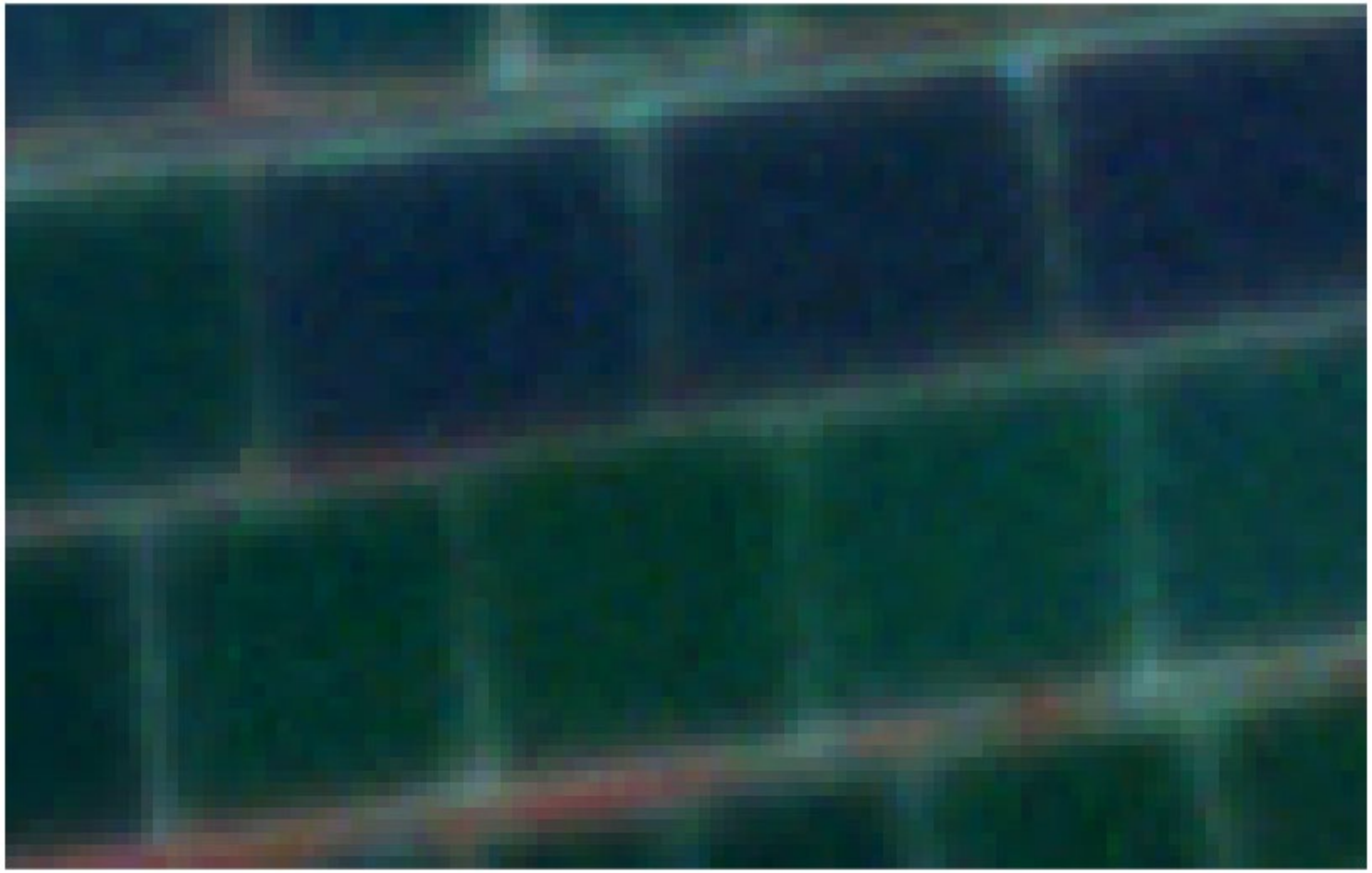
by searching along the two major edge orientations

Algorithm refinement for detection of faint pond edges

Extracted ponds

Algorithm refinement for detection of faint pond edges

PlanetScope 3m image (NIR, red, green)



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Data used for Central Thailand (185 x 92 km)

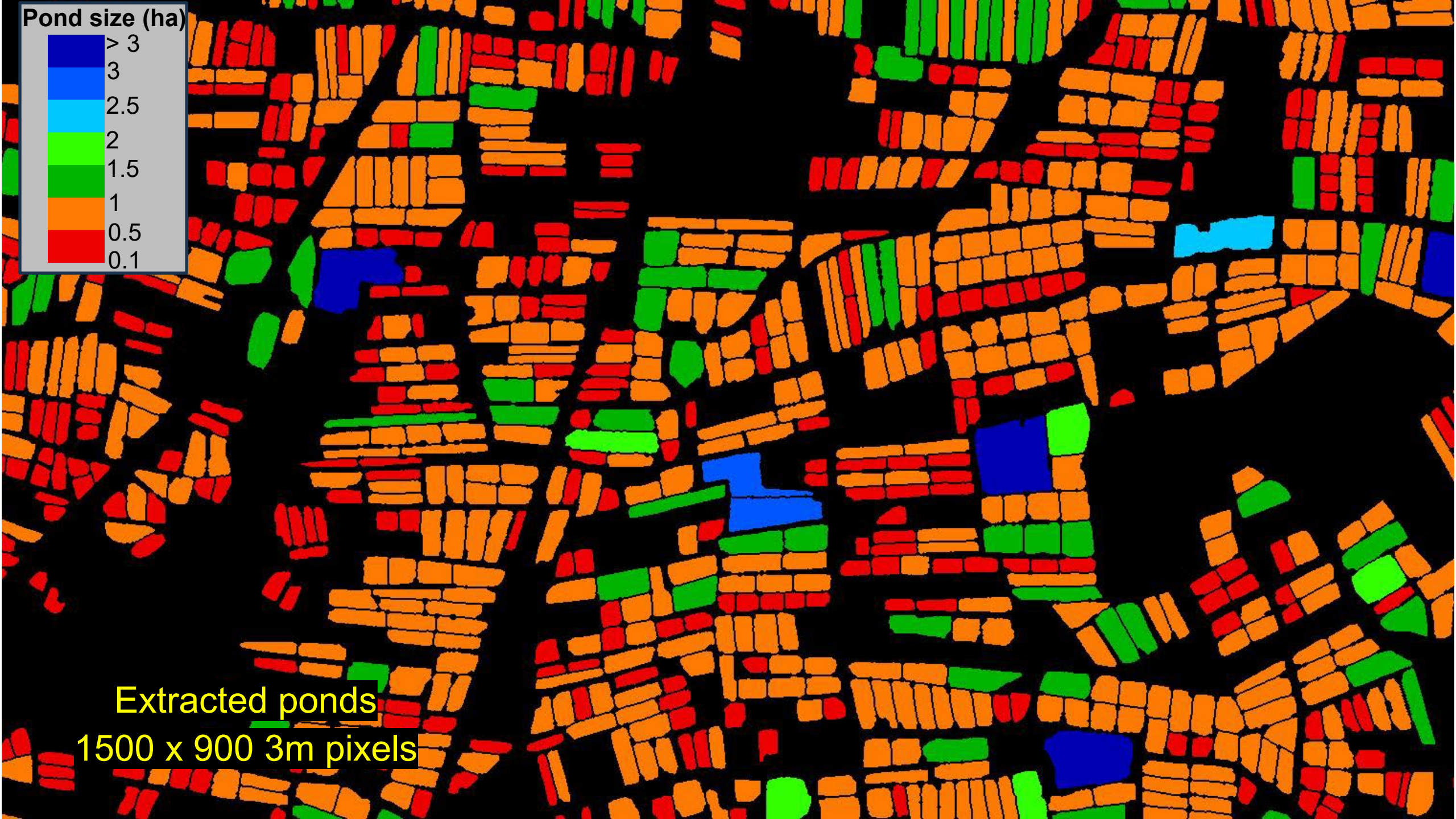
PlanetScope Sentinel-2 harmonized mosaic product

NIR, red, green

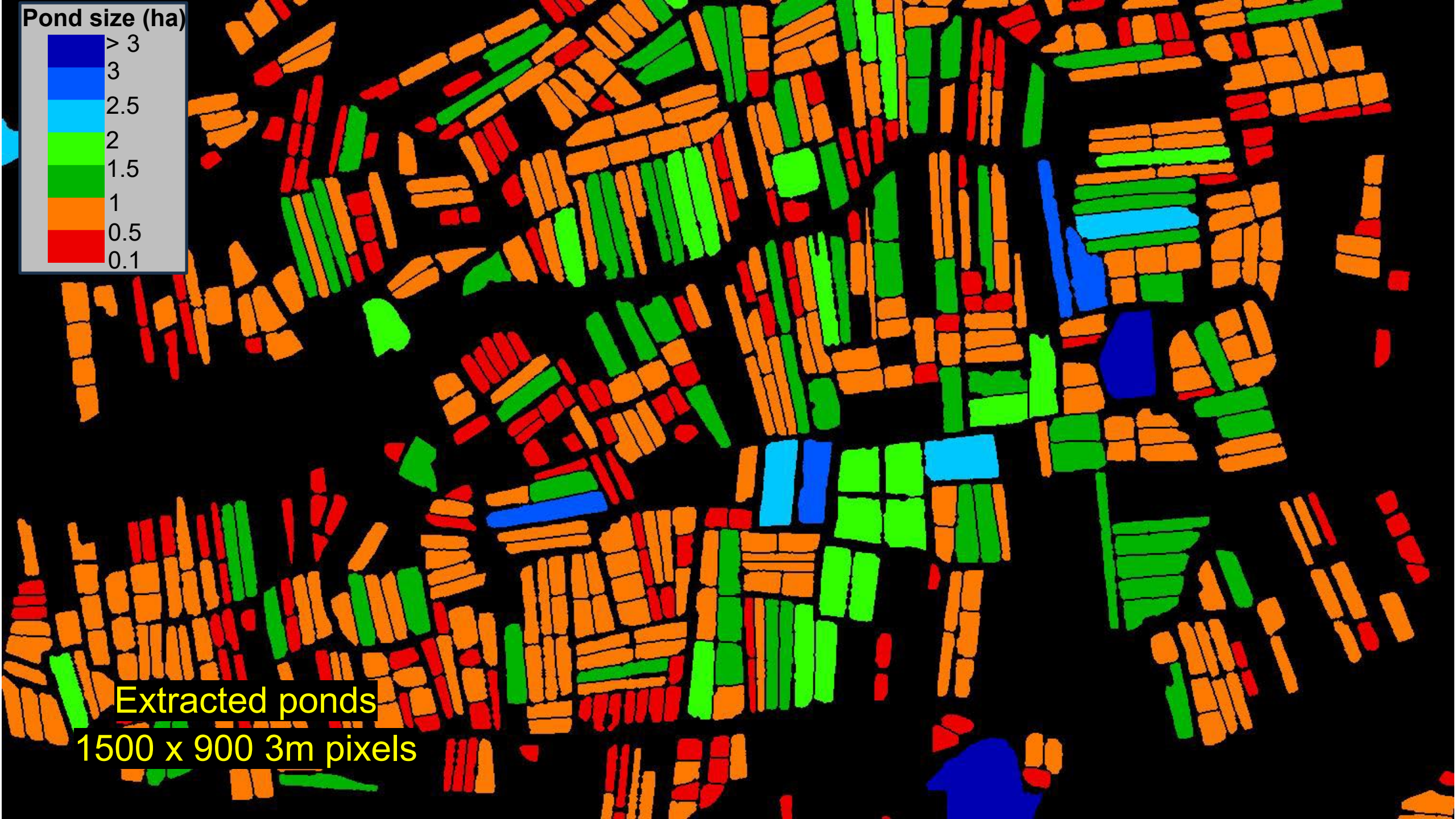
61,500 x 30,500 3m pixels

Acquired January 26-27, 2023


Example PlanetScope image
1500 x 900 3m pixels
false-color (NIR, red, green)


Pond size (ha)
> 3
3
2.5
2
1.5
1
0.5
0.1
Extracted ponds
1500 x 900 3m pixels


Example PlanetScope image
1500 x 900 3m pixels
false-color (NIR, red, green)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2.5
2
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1
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0.1
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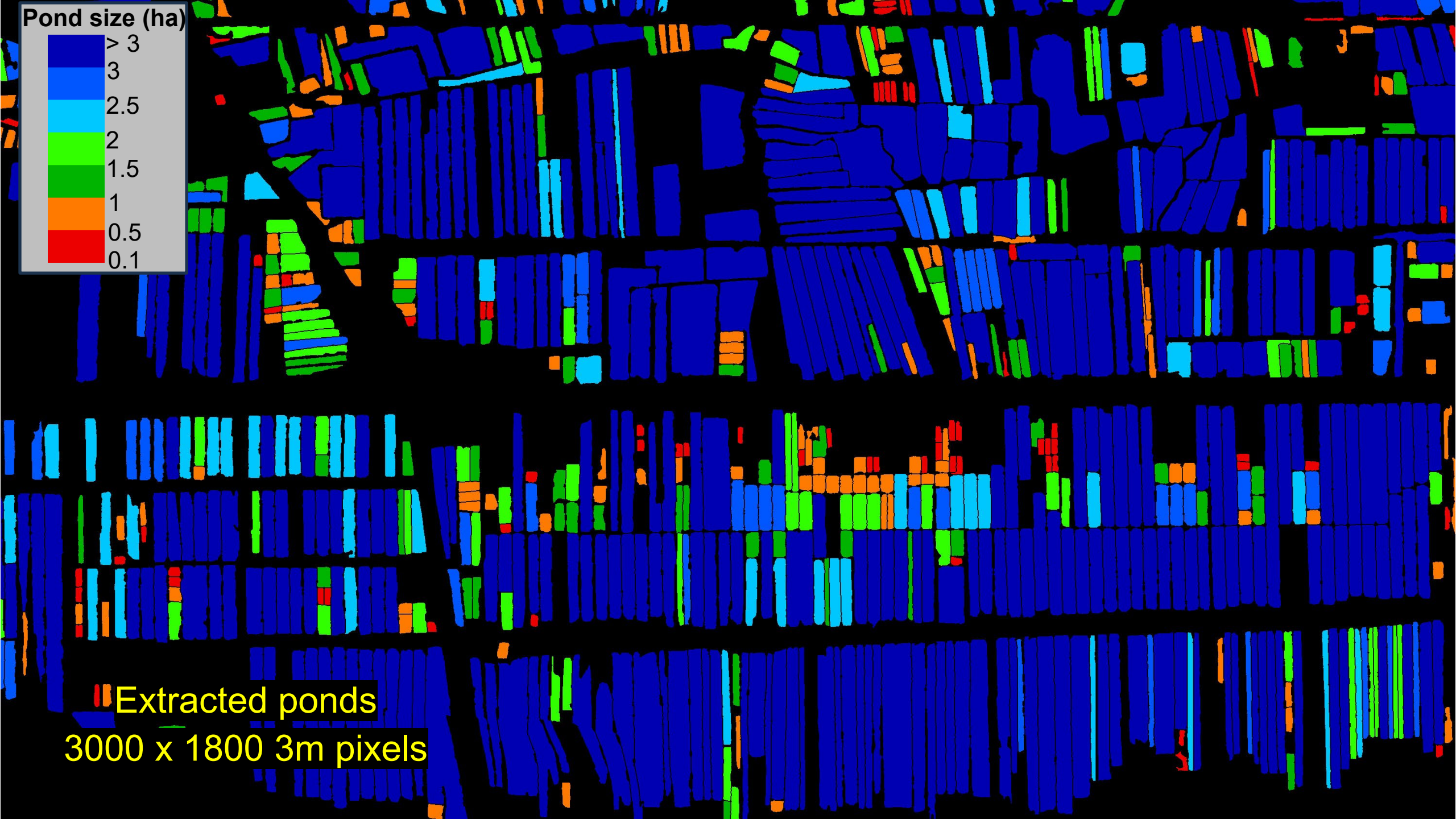
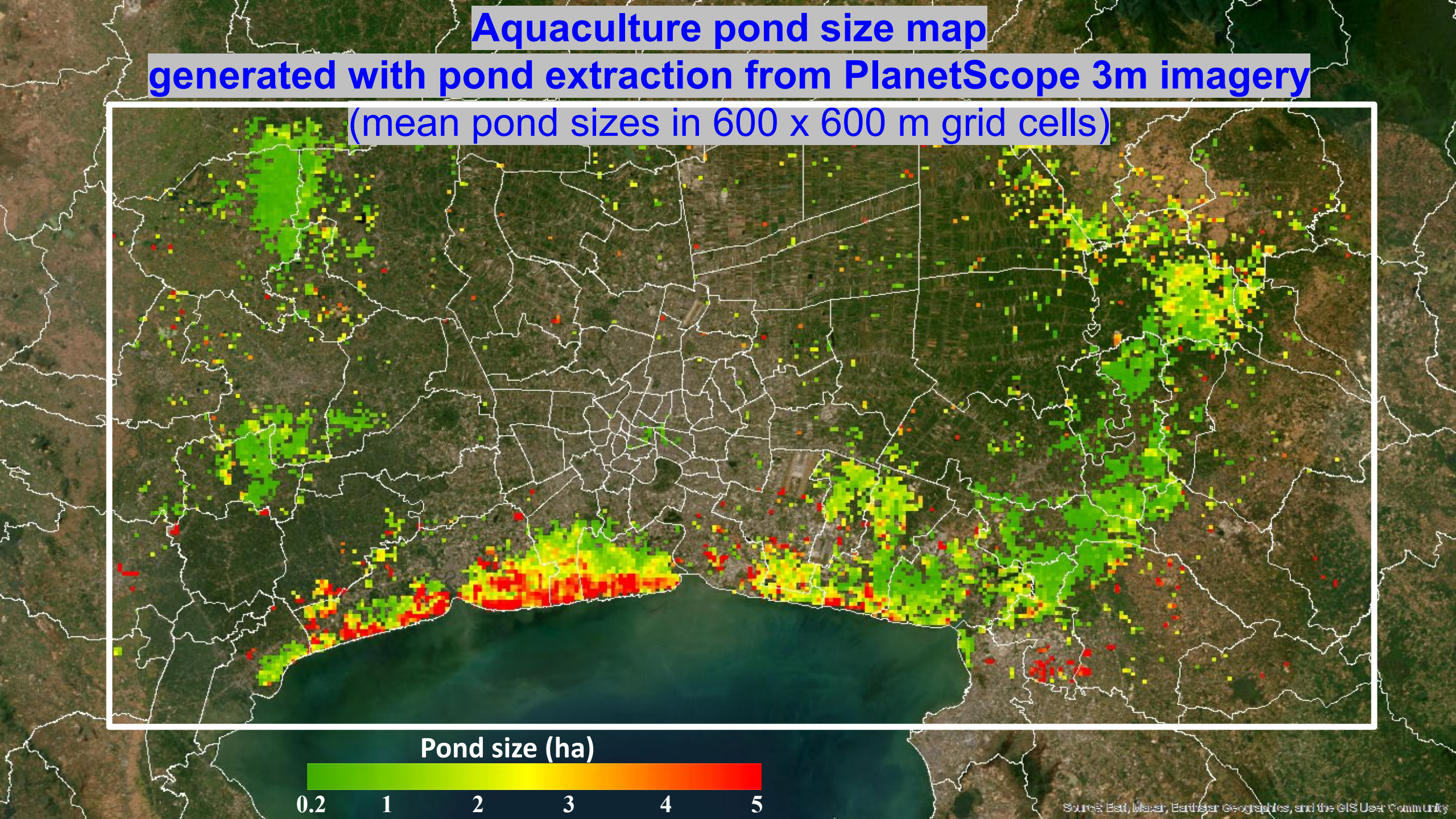
Example PlanetScope image
3000 x 1800 3m pixels
false-color (NIR, red, green)


Pond size (ha)
> 3
3
2.5
2
1.5
1
0.5
0.1
Extracted ponds
3000 x 1800 3m pixels

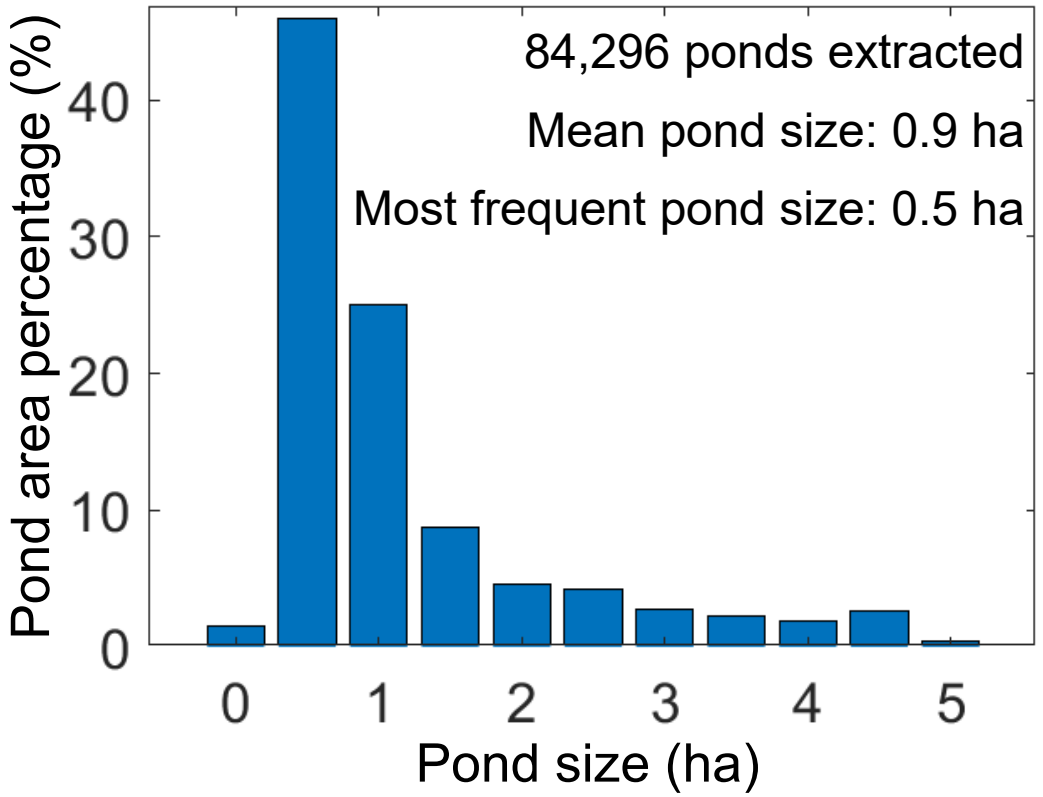
Aquaculture pond size map generated with pond extraction from PlanetScope 3m imagery

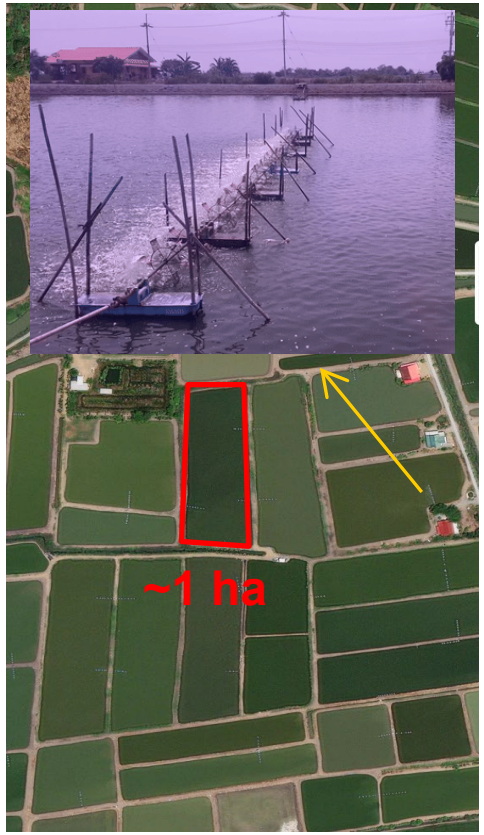
(mean pond sizes in 600 x 600 m grid cells)



Pond size histogram

Extensive farming





Intensive farming

Pond size is a general indicator of aquaculture farming system types (Chamberlain 2010)

- ~ >3 ha: **extensive farming** (low operating cost and low yield, typically in costal areas)
- ~ 1-3 ha: **semi-intensive farming** (drainable ponds, higher yield)
- ~ < 1 ha: **intensive farming** (drainable ponds, aeration device, automated feeder, high stocking density with more water exchange, high investment and high yield)

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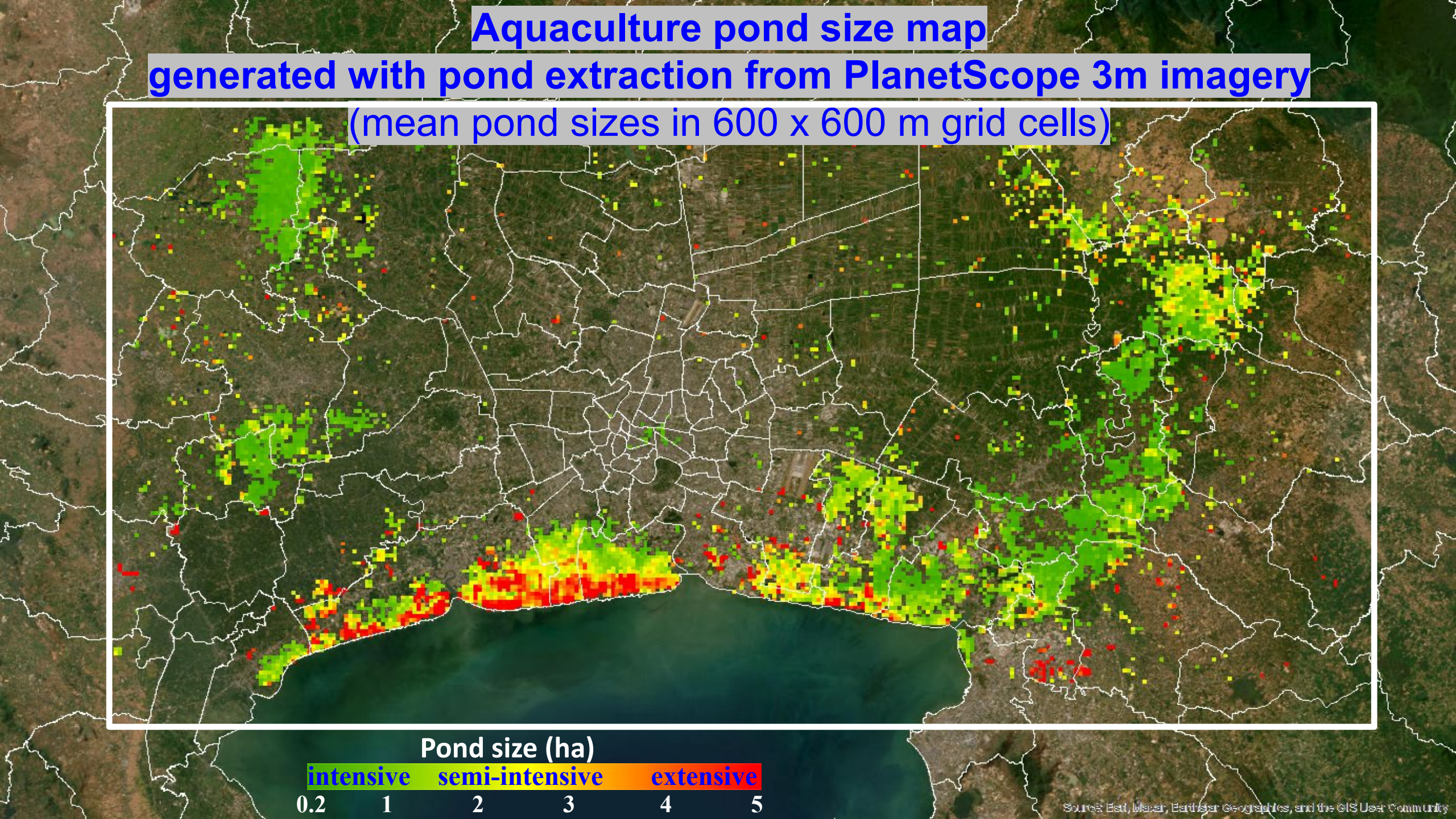
generated with pond extraction from PlanetScope 3m imagery
(mean pond sizes in 600 x 600 m grid cells)



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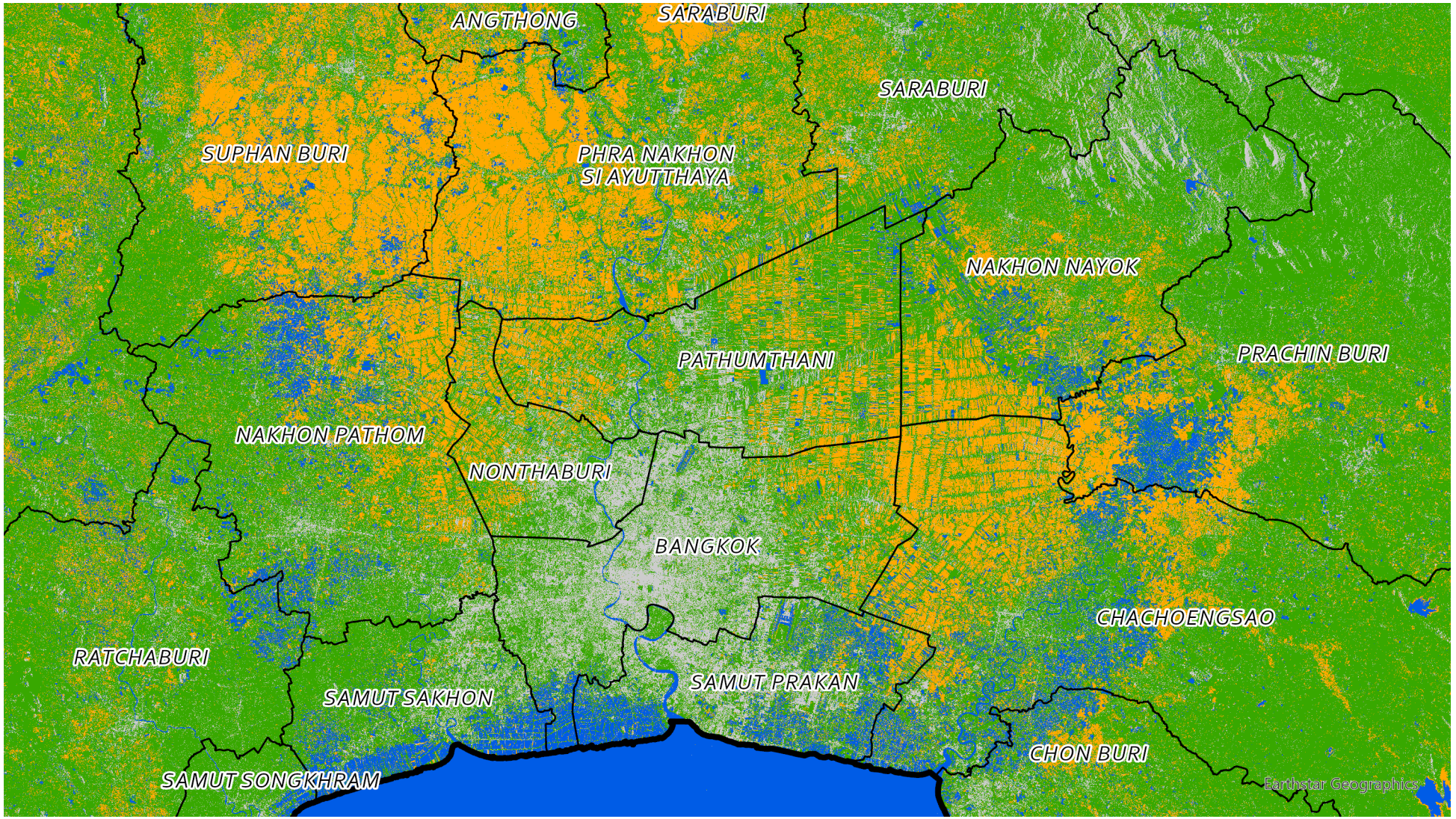
Coarse 4-class 10 m classification of Central Thailand (based on 2021 Sentinel-1 time series)

Rice

Water/ Aquaculture

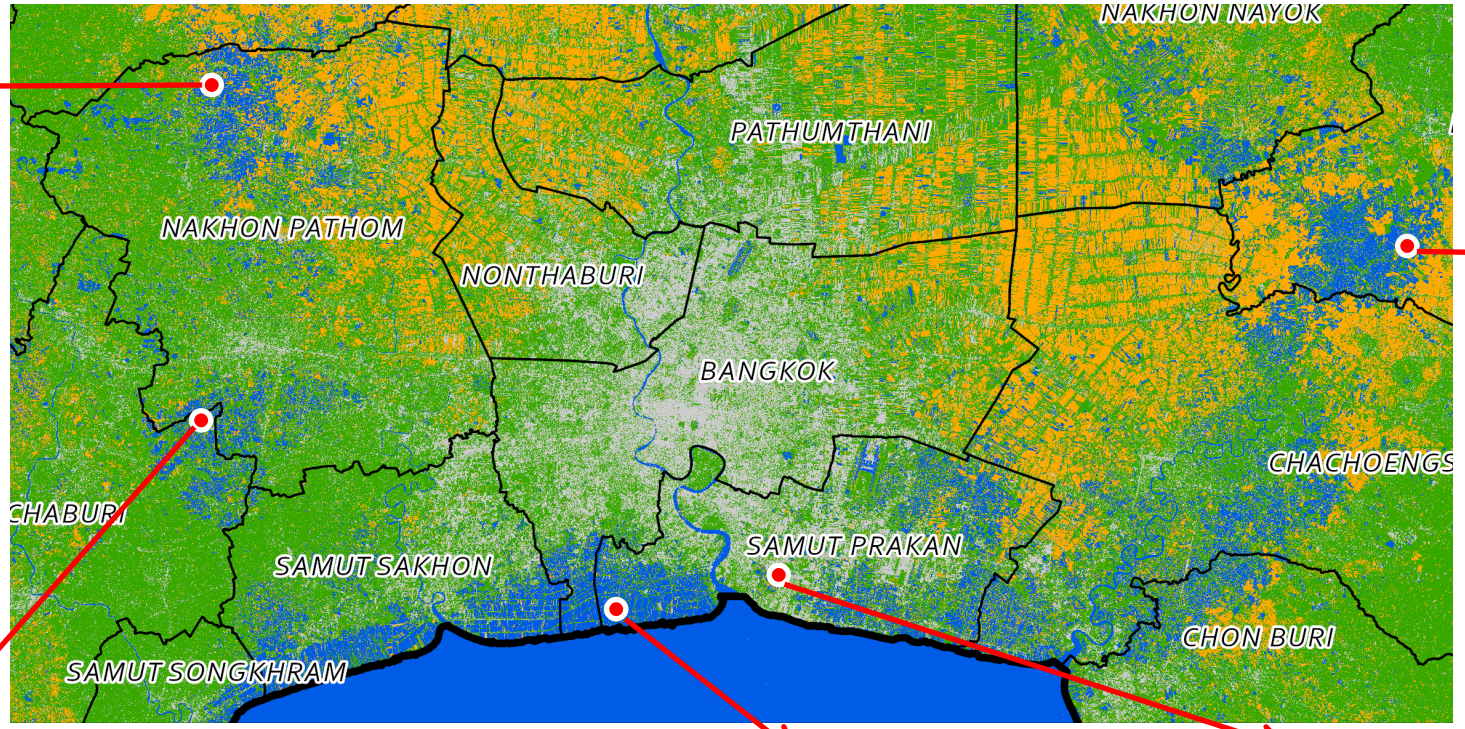
Other vegetation

Urban



Survey locations include different aquaculture context/changes

Inland aquaculture mixed with rice



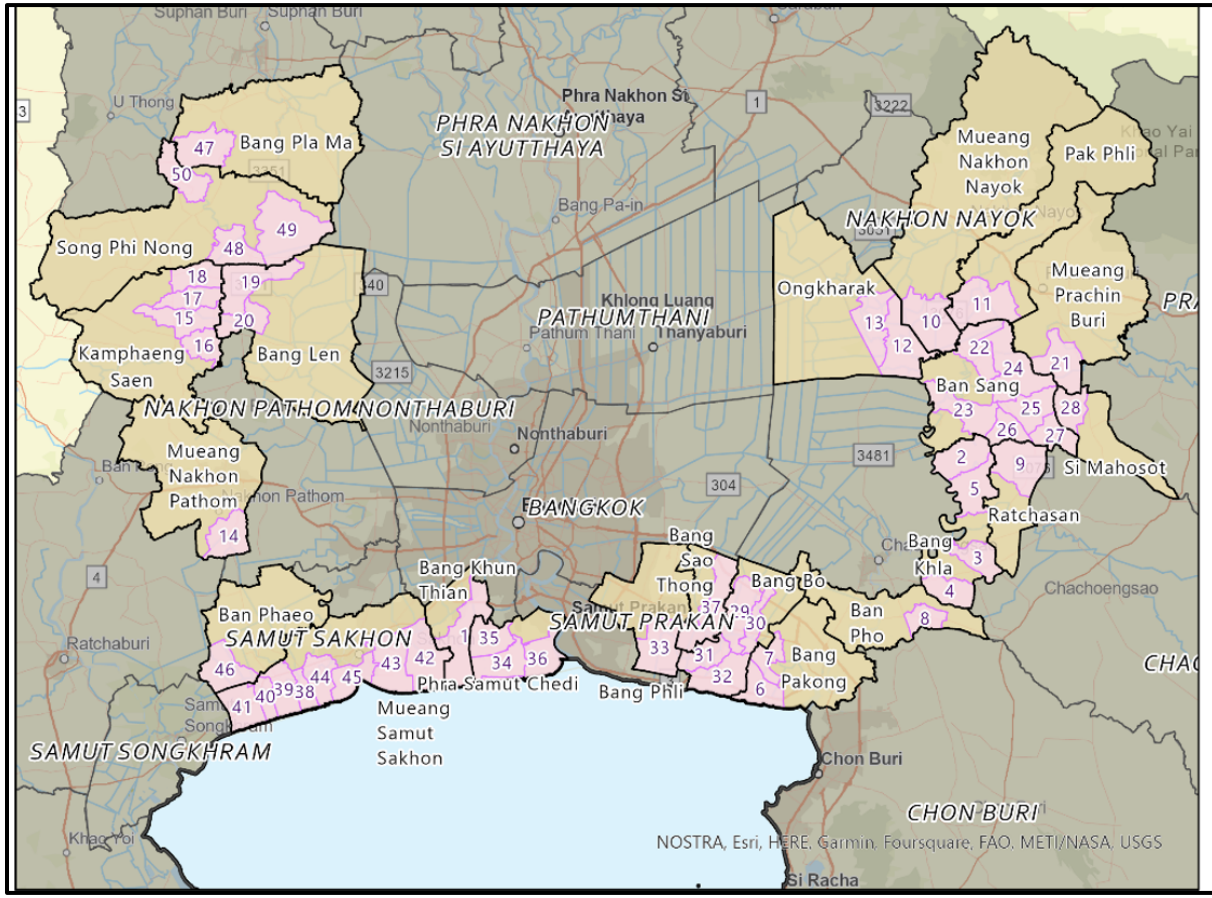
Inland aquaculture mixed with rice

Inland aquaculture mixed with orchard crops (coconut, pomelo, banana, mango...)

Coastal aquaculture

Aquaculture mixed with urban

400 farms in 50 tambons surveyed in Central Thailand



Tambon	No.	Tambon	No.
Tha Kham	1	Bang Kham	26
Bang Krachet	2	Krathum Phaeo	27
Tha Thong Lang	3	Phai Chalueat	28
Samet Tai	4	Bang Bo	29
Hua Sai	5	Ban Rakat	30
Song Khlong	6	Bang Phriang	31
Hom Sin	7	Khlong Dan	32
Sip Et Sok	8	Bang Pla	33
Dong Noi	9	Na Kluea	34
Si Chula	10	Ban Khlong Suan	35
Tha Ruea	11	Laem Fa Pha	36
Bang Sombun	12	Bang Sao Thong	37
Bang Luk Suea	13	Ban Bo	38
Don Yai Hom	14	Bang Thorat	39
Sa Si Mum	15	Kalong	40
Don Khoi	16	Na Khok	41
Sa Phatthana	17	Phanthai Norasing	42
Huai Muang	18	Khok Kham	43
Bang Luang	19	Bang Krachao	44
Phai Hu Chang	20	Bang Ya Phraek	45
Bang Decha	21	Rong Khe	46
Ban Sang	22	Wat Bot	47
Bang Yang	23	Bang Len	48
Bang Phluang	24	Bang Ta Then	49
Bang Pla Ra	25	Hua Pho	50

- 8 provinces identified using government statistics on aquaculture area per province
- 50 tambons (in the 8 provinces) selected based on the 2021 land cover map
  - high aquaculture-area percentage
  - different types of aquaculture context/changes (coastal, near-urban, mixed with rice or orchard crops…)

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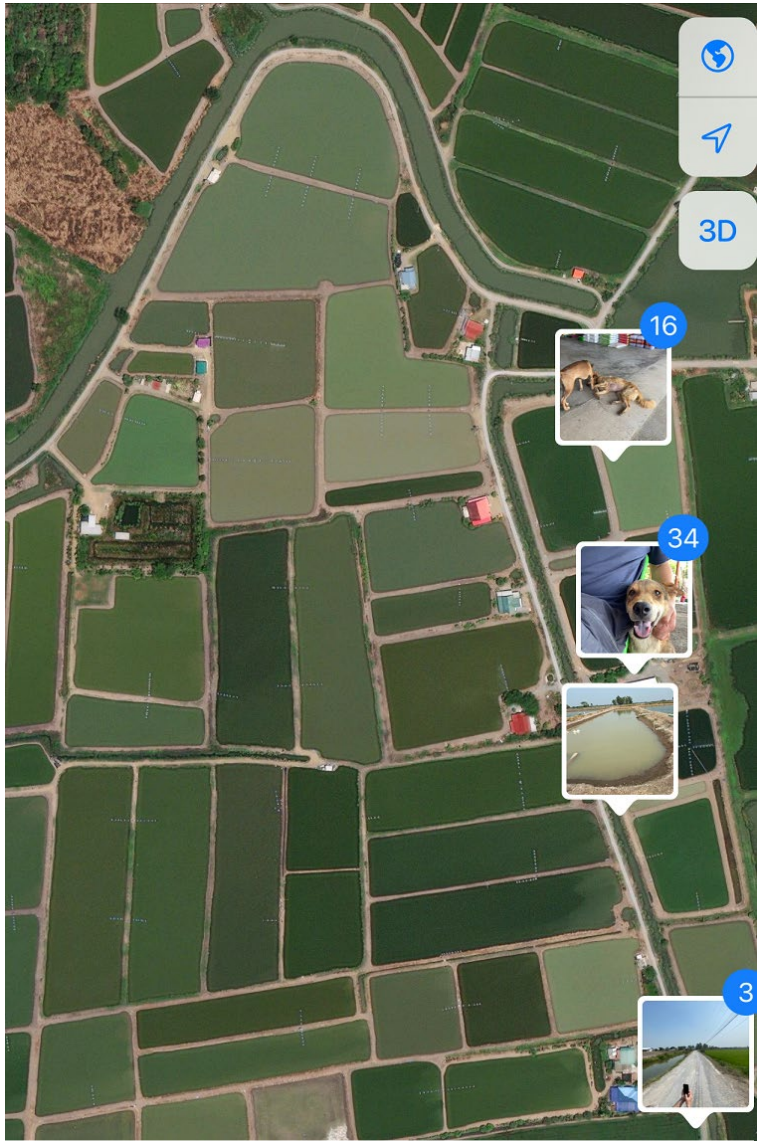
Social surveys

- Collected information on
  - history of land use change on each farm
  - factors affecting farmer decisions on aquacultural LCLUC
- Questionnaire with multiple modules
  i) household characteristics
  ii) land ownership, rental, use for aquaculture and non-aquaculture purposes;
  iii) history of and reasons for historical acquisition and/or disposal of owned and rented parcels of aquaculture land
  iv) events occurring in respondents' most successful and least successful years of aquaculture production;
  v) history of conversion of land between different uses and physical modification of ponds
  vi) history of aquaculture farming technology adoption
  vii) farming cycles and calendar…

Survey Timeline

Date (2023)	Work	Personnel and corporation
Feb.	• set up IRB • drafted survey questionnaire with remote sensing components	Ben, Lin, David
Mar.	• kick-off meeting in Thailand • pre-tested the draft questionnaire in Nakhon Pathom province, Thailand	Ben, Lin, David, Leo, Ora, Phring
June	• pre-tested the digital version of the draft questionnaire in Samut Sakorn, Suphanburi, and Chachoengsao provinces, Thailand • finalized Thai language translation of the questionnaire	Ben, Leo, Phring, Kae, Pui
Aug.	• worked out the sampling strategy for the India survey	Ben, Seafood Solutions
Aug.	• finalized Telegu language translation of the questionnaire • trained enumerators	Seafood Solutions
Sept.	• held a meeting at Kasetsart University to decide final sampling strategy for the Thai survey	Ben, Ora, Phring, Kae, Pui
Sept. - Dec.	• conducted surveys in 400 aquaculture farms in Andhra Pradesh province, India	Seafood Solutions
Oct. - Dec.	• conducted surveys in 400 aquaculture farms in 8 provinces in Thailand	Ben, Ora, Phring, Kae, Pui

• Ben, Lin, David, Leo: MSU, USA • Ora, Phring, Kae, Pui: Kasetsart Univ., Thailand • Seafood Solutions: India



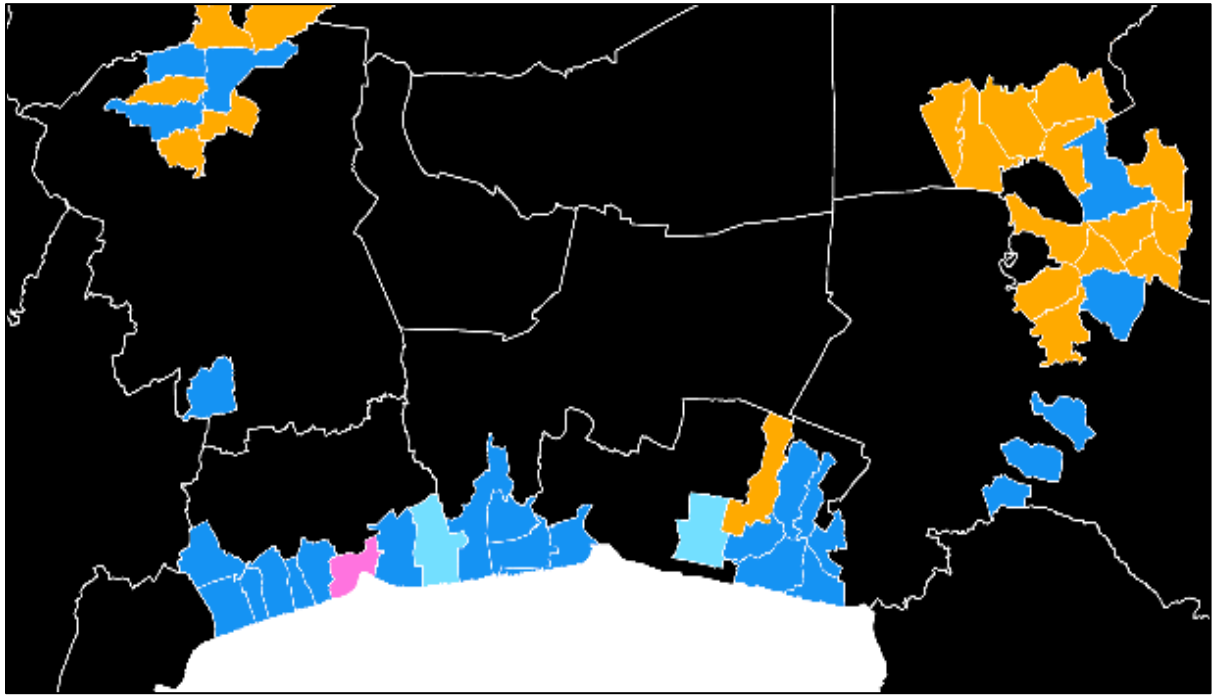
Screenshot of my cellphone

Survey pre-test (inland intensive aquaculture farm in Nakhon Pathom, Thailand March 30th 2023)

Preliminary survey results: land use change

Tambo-level result derived from:

- date of parcel acquisition/disposal
- previous land use before parcel acquisition/disposal
- current land use (in 2023)
- parcel size



"Rice farming" → "aquaculture" (*n* = 19)

"Aquaculture" (unchanged) with increased pond area (*n* = 26)

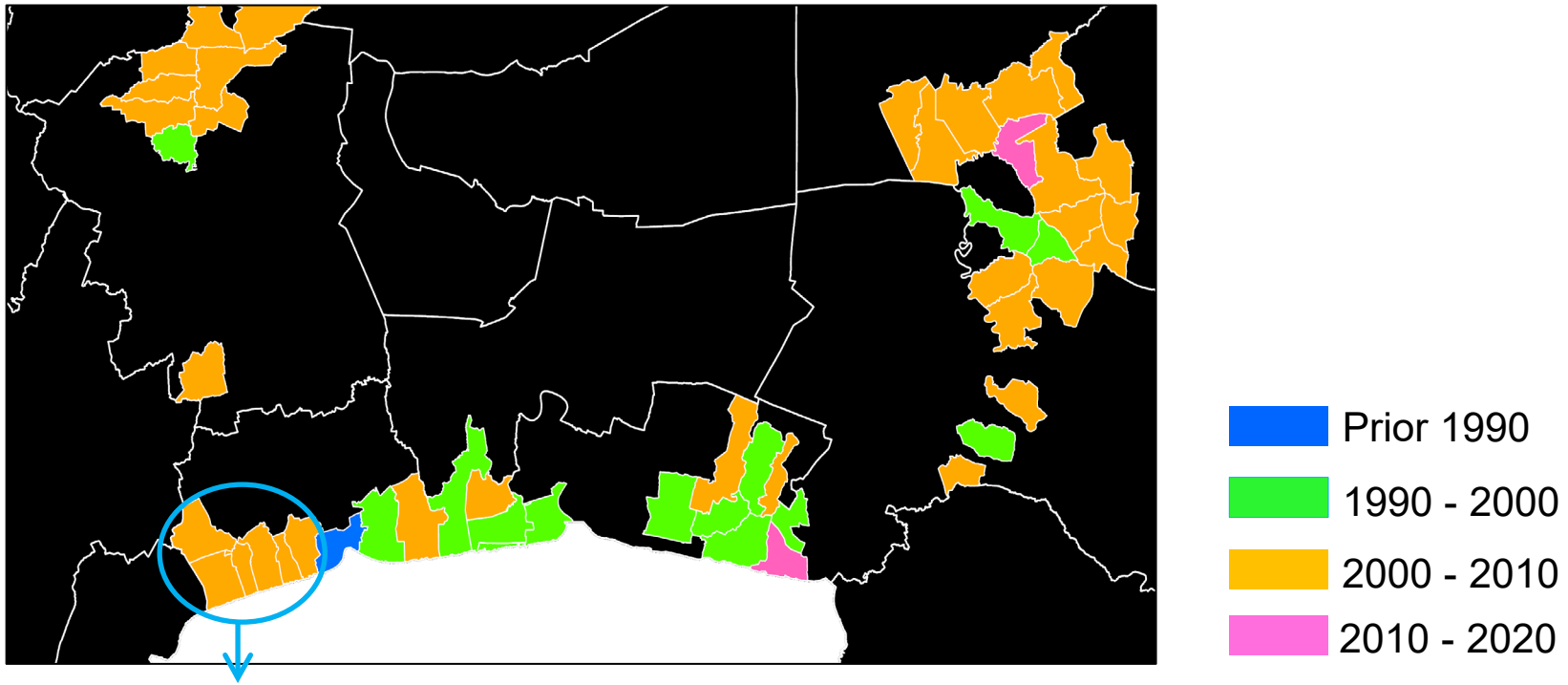
"Aquaculture" (unchanged) with decreased pond area (*n* = 2)

"Salt pan and aquaculture" (unchanged) (*n* = 1) (combined land use in the same parcel)

Preliminary survey results: starting year of aquaculture

Tambo-level result derived from:

- date of aquaculture parcel acquisition



Seemingly late start (**2000-2010**) for the coastal region

Due to shrimp aquaculture collapsed in late **1990s** (for shrimp disease outbreaks)
Restarted after **2000**

Captured by remote sensing (see next)

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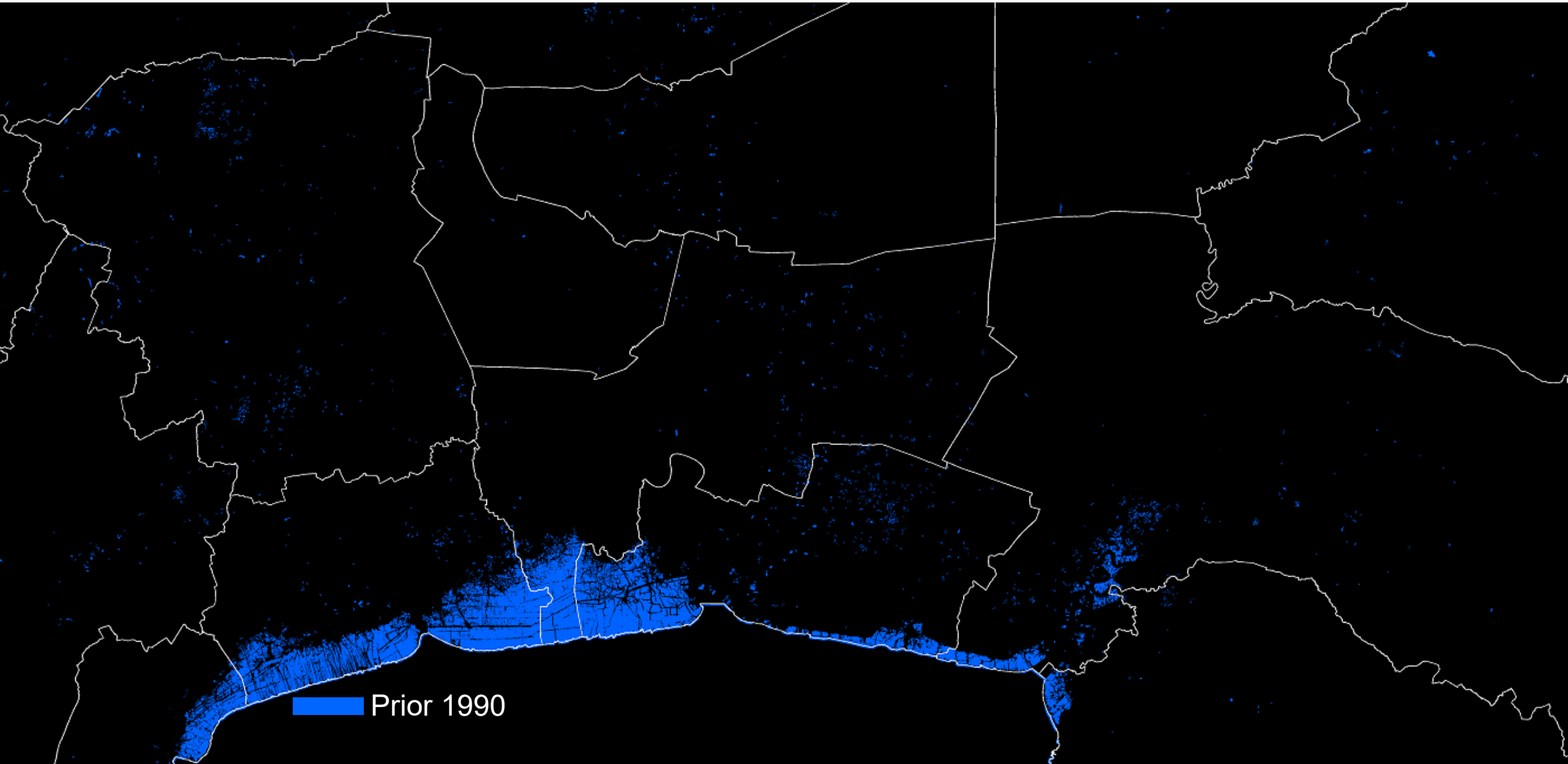
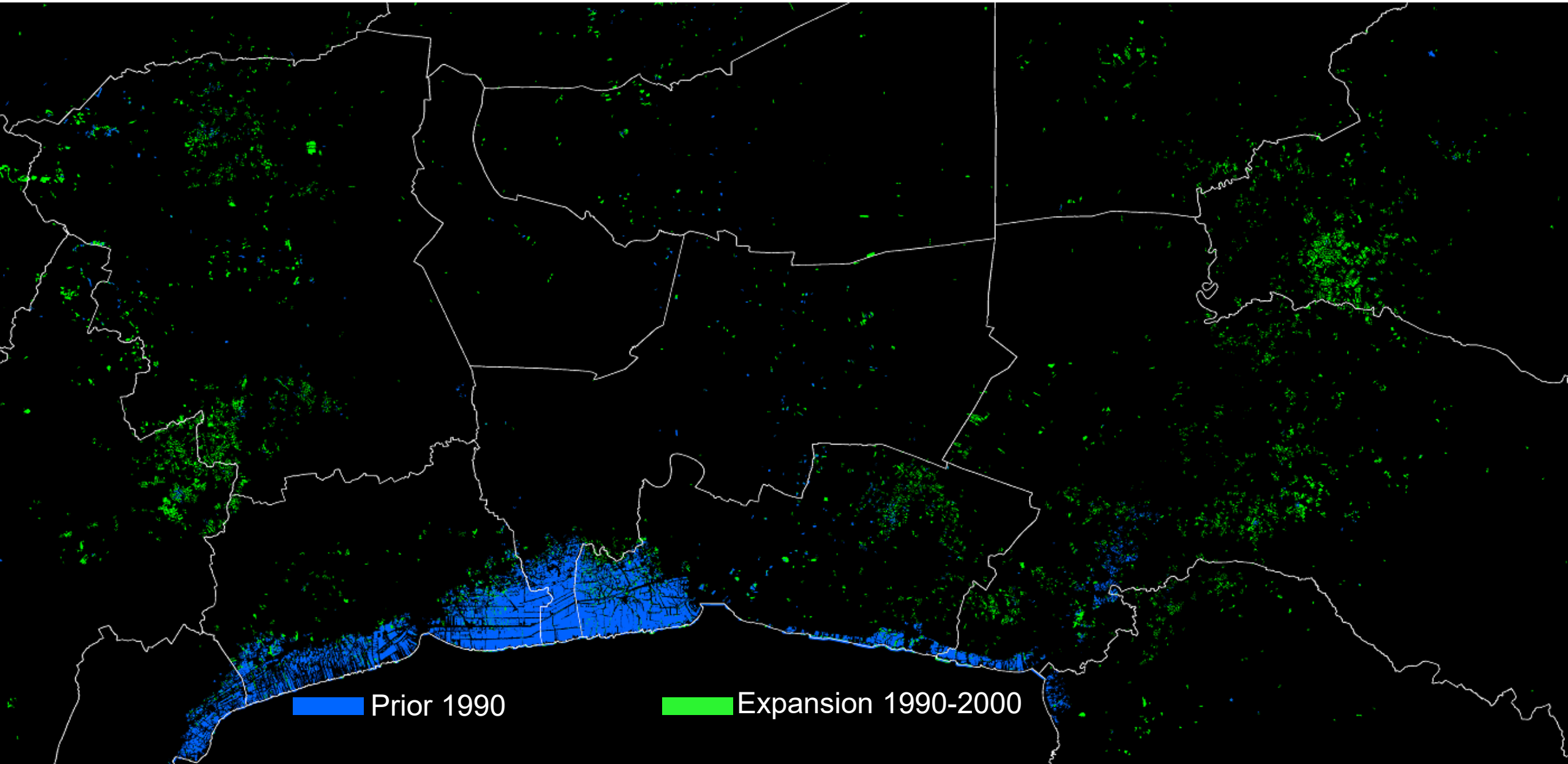
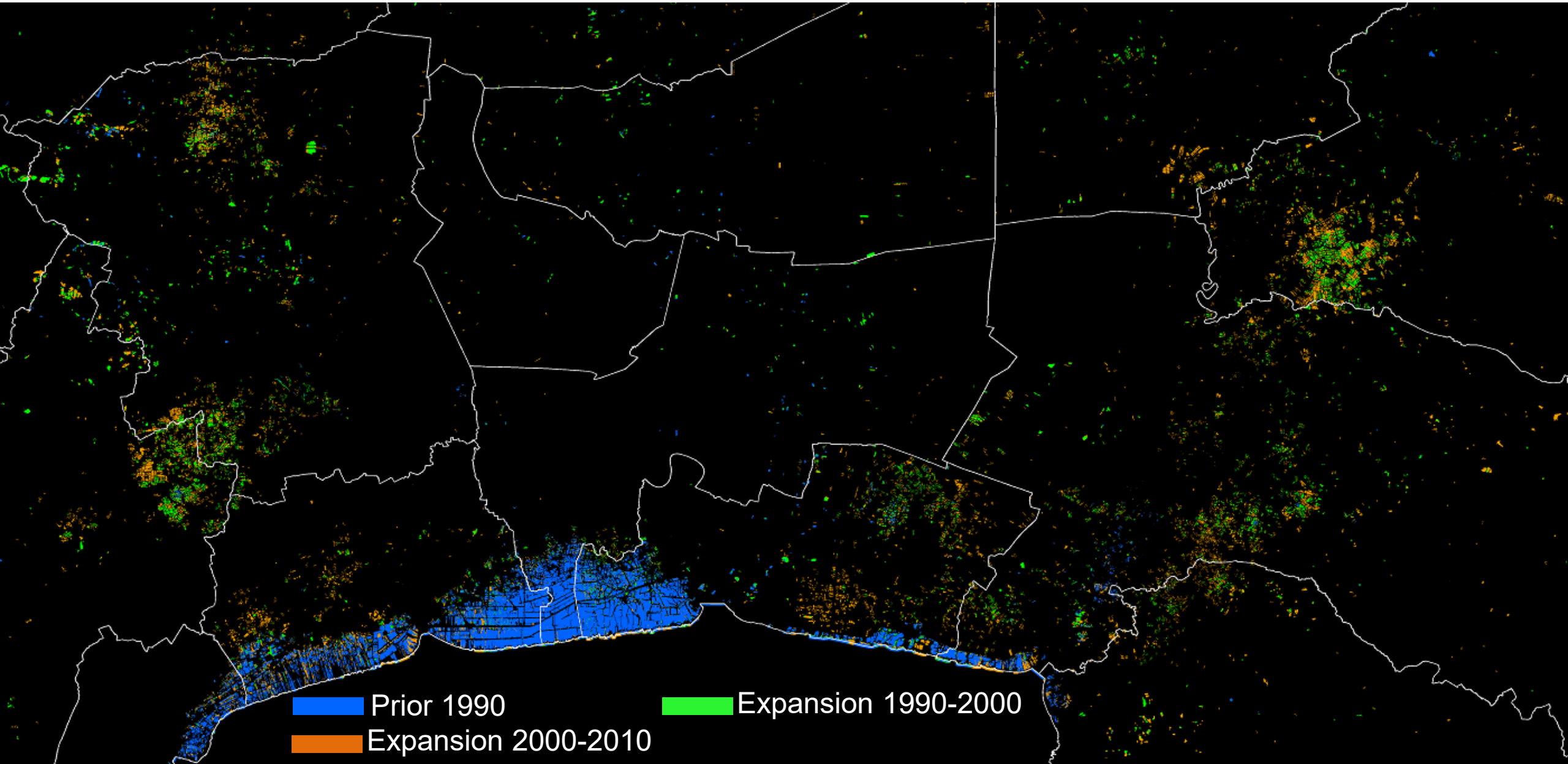
Aquaculture area in Central Thailand – prior 1990



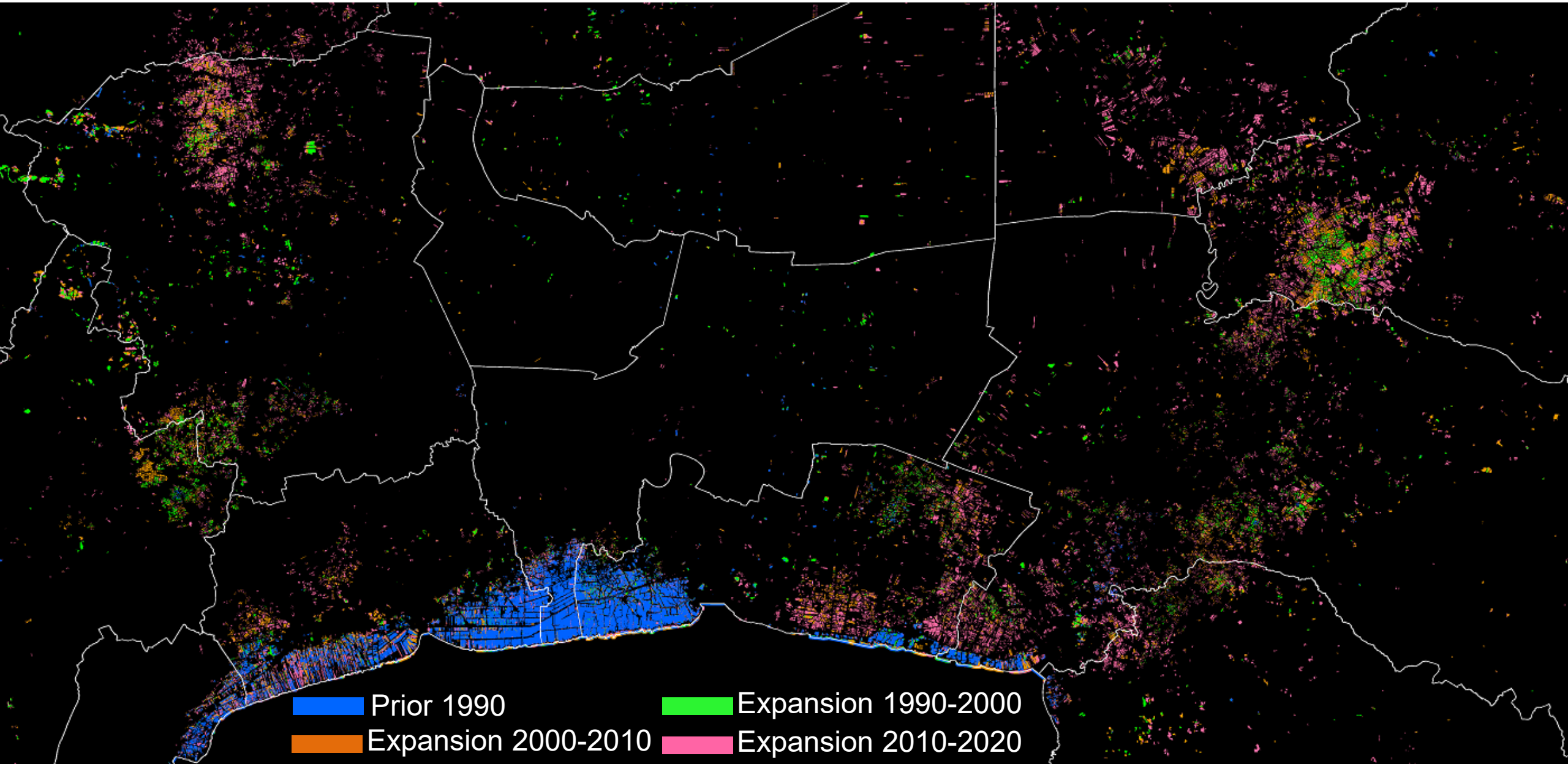
Aquaculture area in Central Thailand – 2000



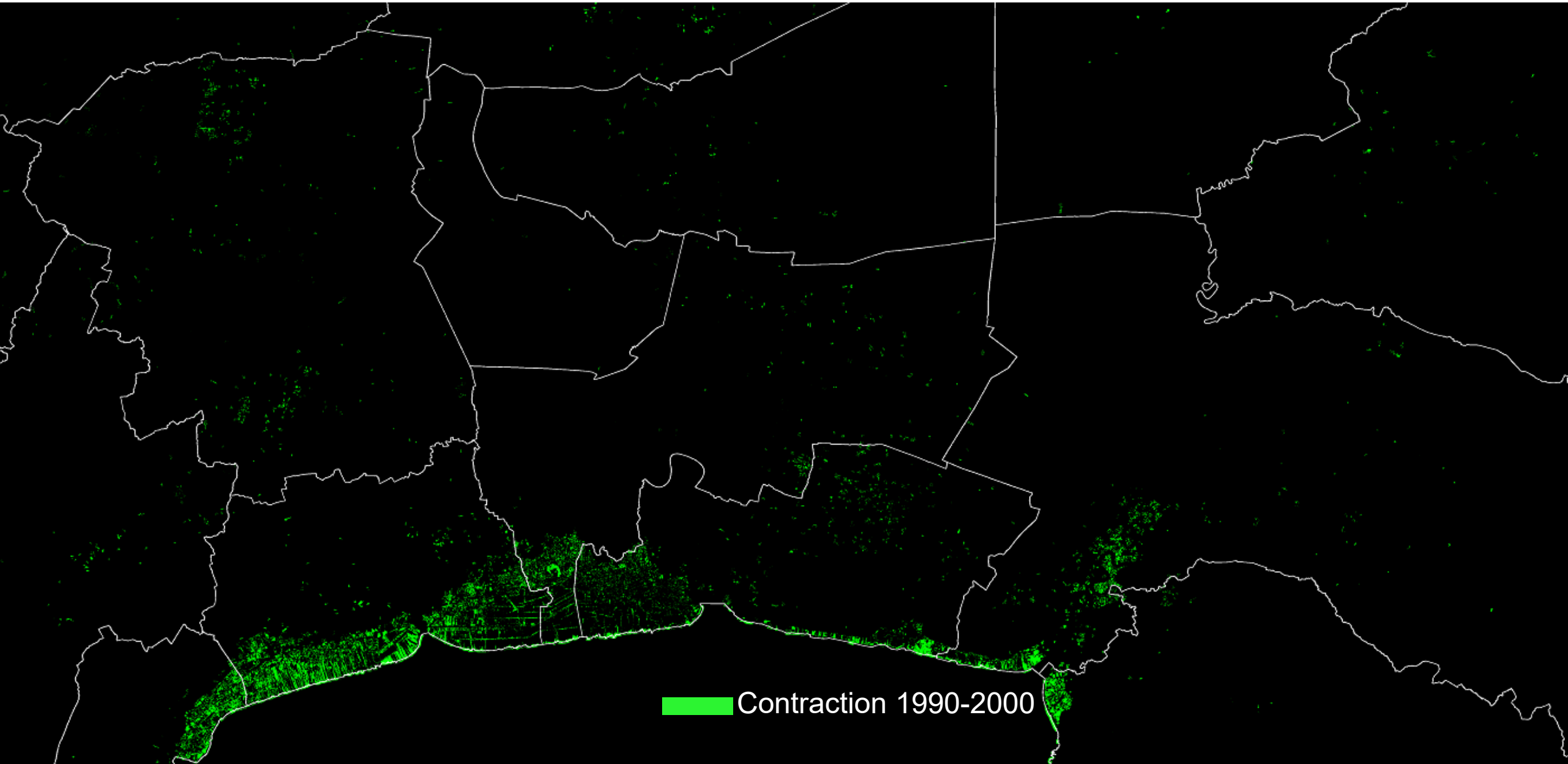
Aquaculture area in Central Thailand – 2010



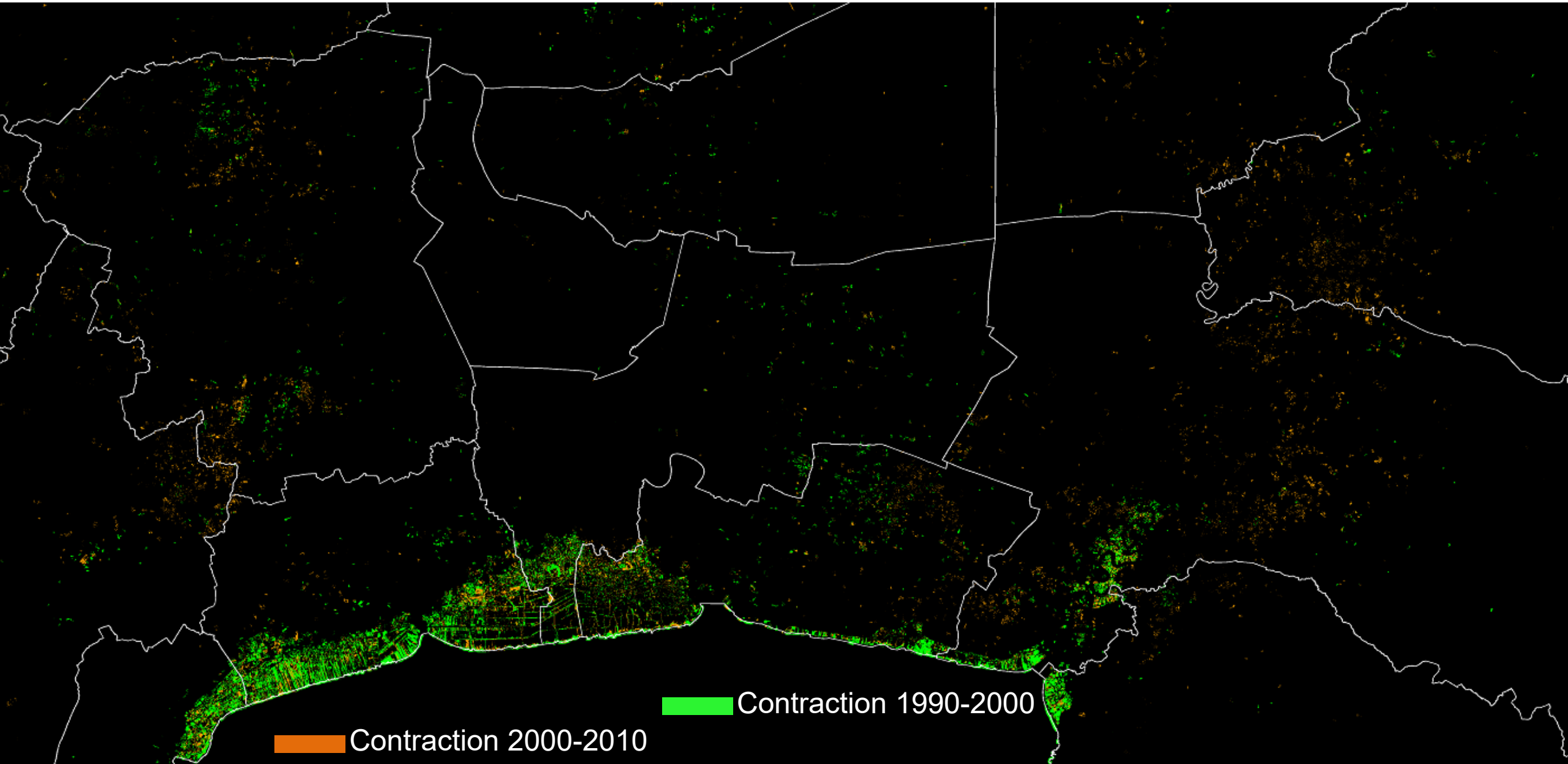
Aquaculture area in Central Thailand – 2020



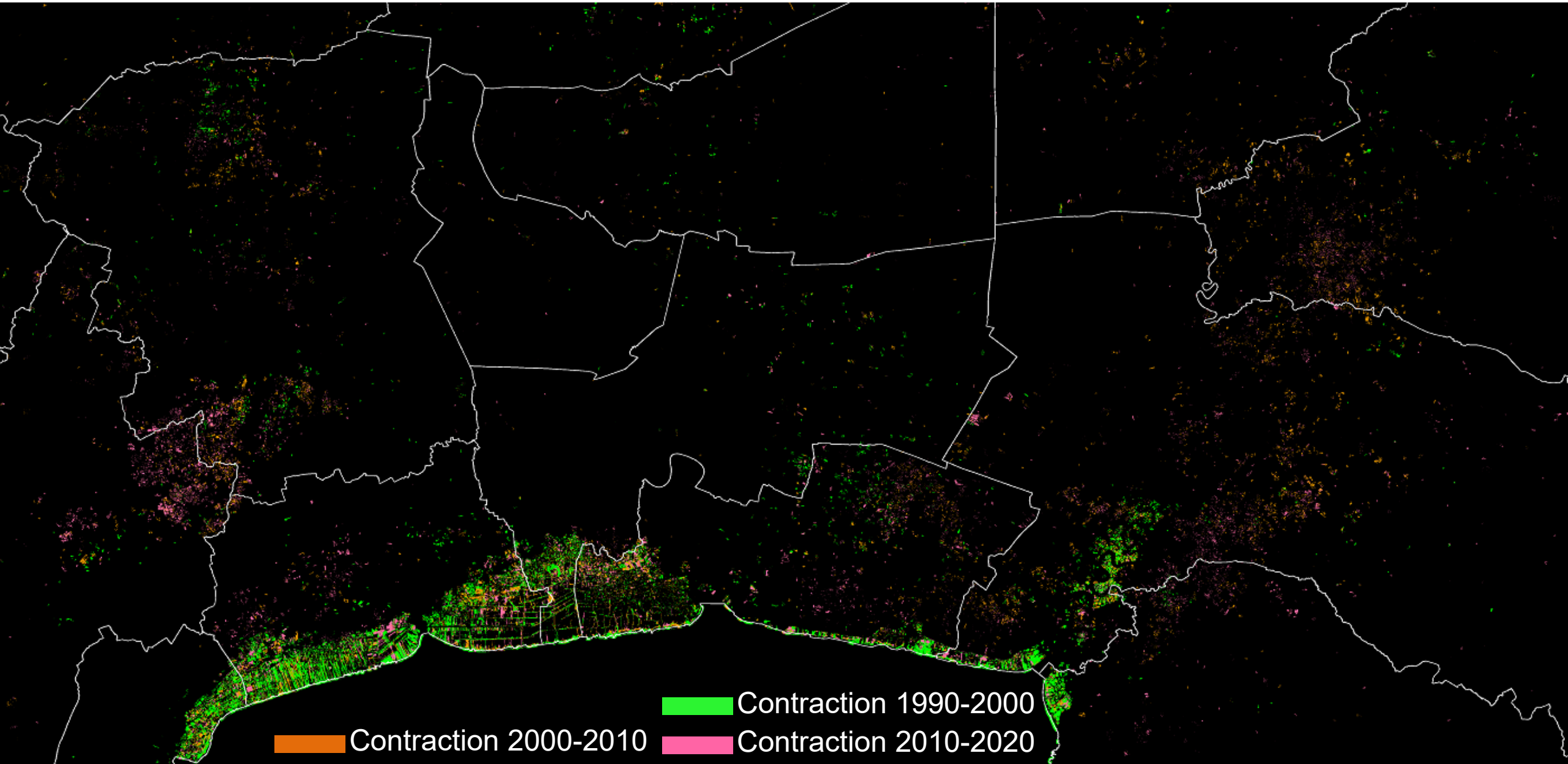
Aquaculture contraction in Central Thailand



Aquaculture contraction in Central Thailand



Aquaculture contraction in Central Thailand



Used the EU Global Surface Water (GSW) product

- Produced by Joint Research Centre (Pekel et al. 2016)
- Derived from 30m Landsat images for years 1984-2021
- Publicly available
- Previously used to map aquaculture areas in Thailand (Dorber et al. 2020; Yan, et al. 2022)
- We used GSW *monthly water-occurrence product* in
    - 1989, 1990,1991
    - 1999, 2000, 2001
    - 2009, 2010, 2011
    - 2019, 2020, 2021

(Yan et al. 2024)

GSW-based aquaculture expansion and contraction

- Water-occurrence frequency for each decade:

$$water\_frequency(i,j) = \frac{\sum_{k=1}^{n} \text{GSW\_monthly}\_water\_occurence_k(i,j)}{\sum_{k=1}^{n} valid\_obs_k(i,j)}$$

- $aquaculture\_area$ = $water\_frequency$ > 0.25 (4 months)

(natural water bodies, e.g. rivers and lakes, were masked off)

- $aquaculture\_expansion_{year1\text{-}year2}$:

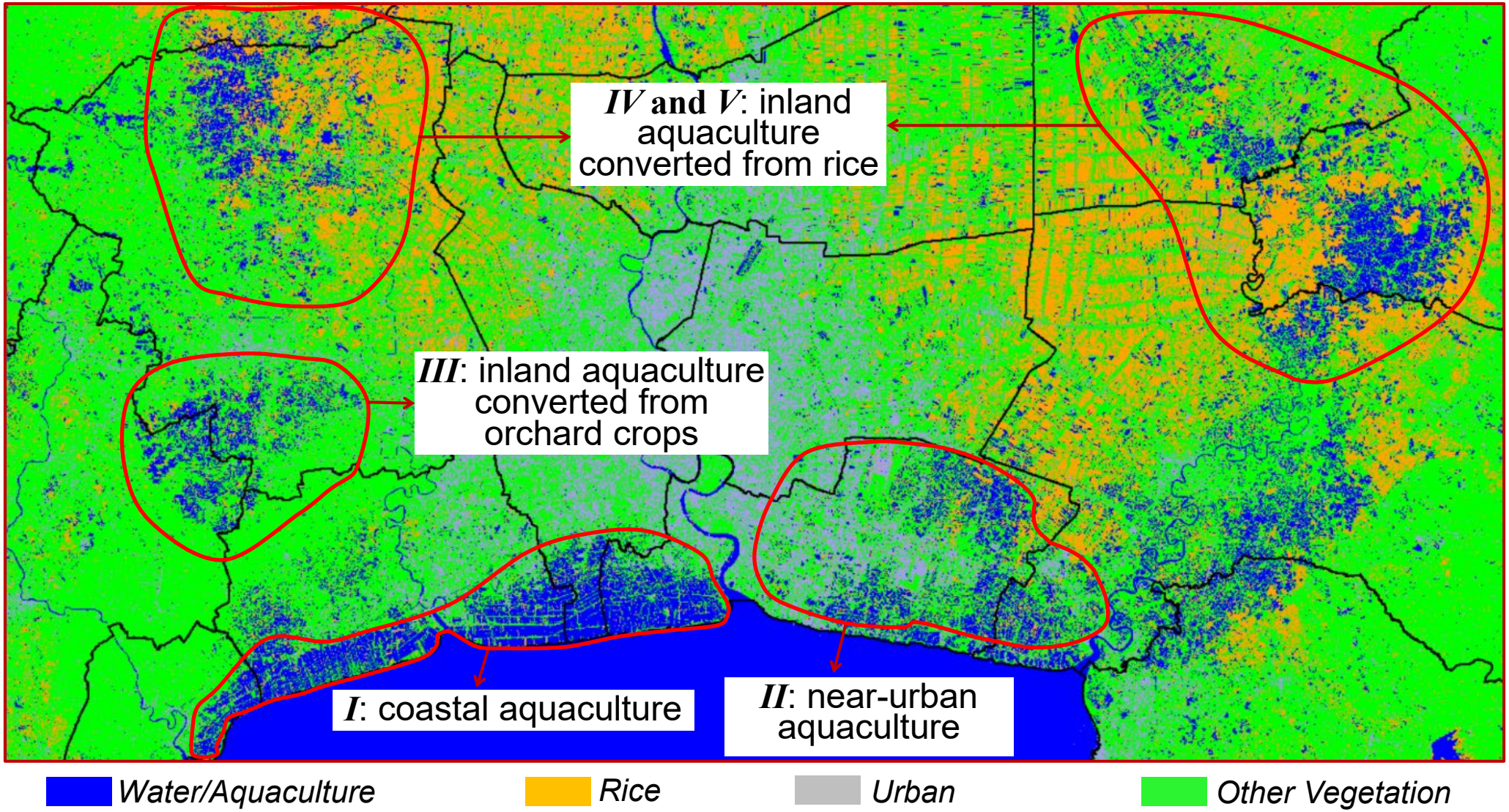
$$aquaculture\_area_{year1} == 0 \quad \& \; aquaculture\_area_{year2} == 1$$

- $aquaculture\_contraction_{year1\text{-}year2}$:

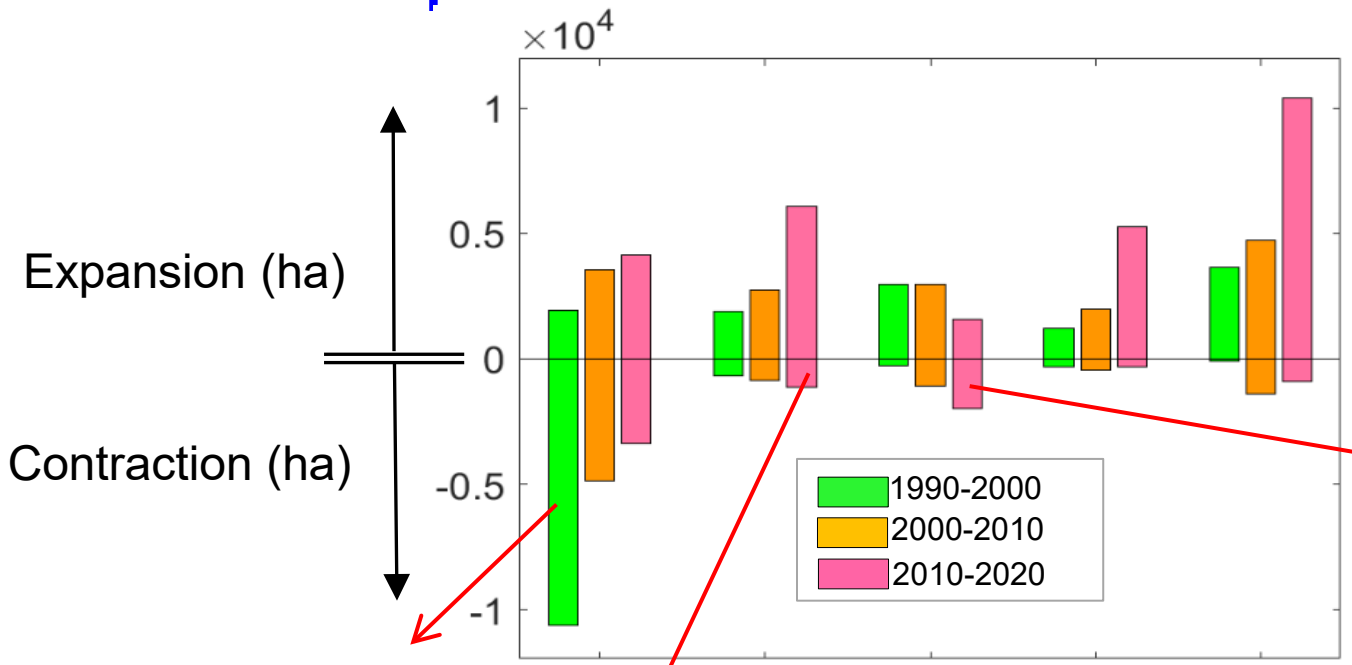
$$aquaculture\_area_{year1} == 1 \quad \& \quad aquaculture\_area_{year2} == 0$$

(Yan et al. 2024)

Five aquaculture zones with 4 different LCLUC context



Aquaculture expansion and contraction in the five zones



Contraction in coastal area due to the outbreaks of the deadly "white spot syndromes" shrimp disease in late 1990s

Contraction in near-urban area due to urbanization

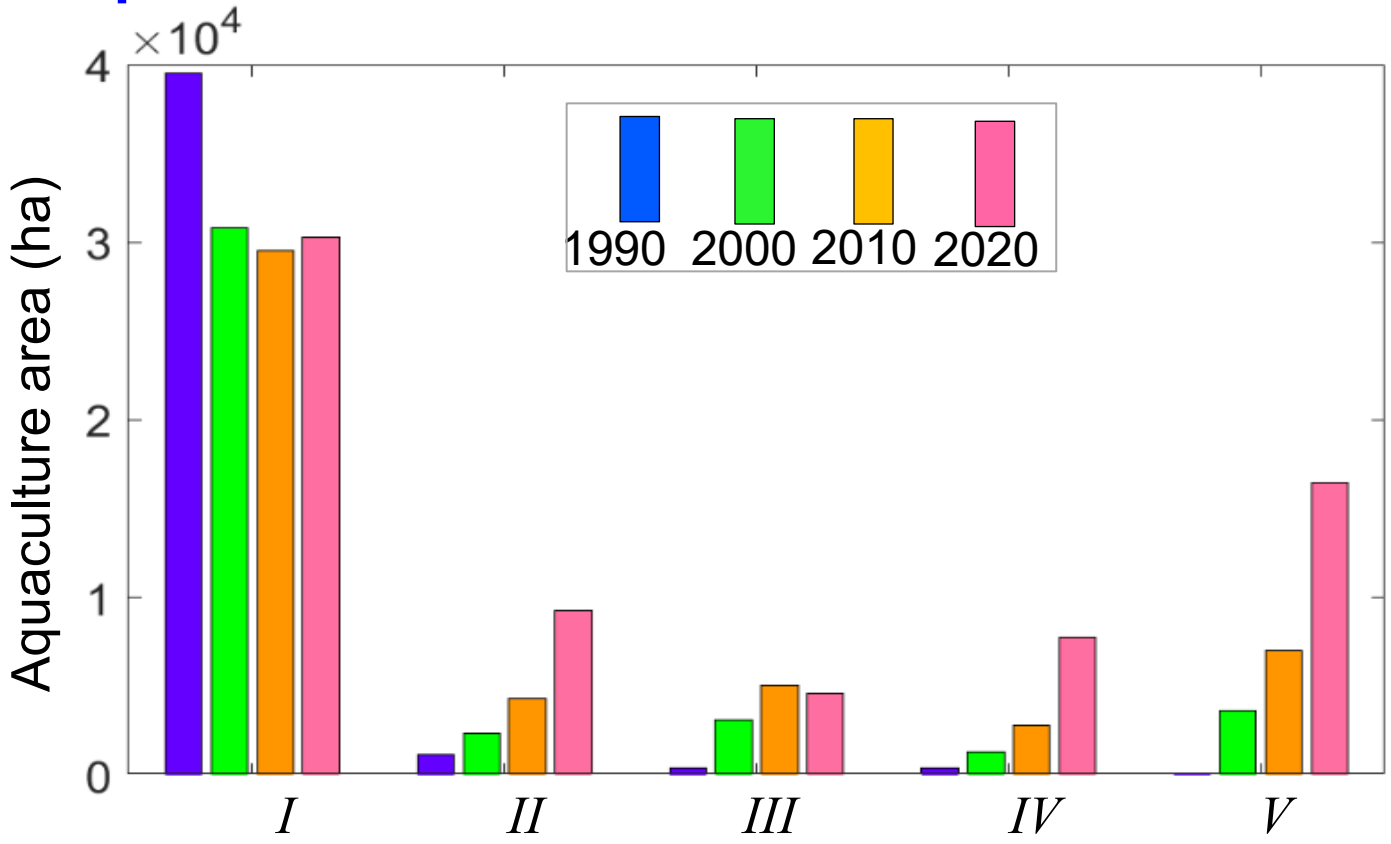
Aquaculture expansion and contraction co-exist regionally

Contraction in orchard-crop area due to

- declined prices of shrimp and fish
- more available migrant labor from Myanmar
- shifted profitability back in favor of some orchard crops, such as coconut and pomelo

More details in book chapter: Yan, L., Belton, B., Roy, D.P., Baldiga, L., Thaneerat, A. (2024). Characterizing aquaculture-associated land cover land use changes in Central Thailand, 1990-2020, in *Remote Sensing of Land Use/Cover Changes in South/Southeast Asian Countries*. Editors: Vadrevu, K.P., Justice, C., Gutman, G.

Aquaculture areas in the five zones



I	II	III	IV	V
Coastal aqua.	Near-urban aqua.	Inland aqua. converted from orchard crops	Inland aqua. converted from rice	
Projected trends: remain stable	Increase but may slow down	likely decrease	increase	

The issues will remain (competition for water, water pollution, soil salinization,…)

Preliminary results. Will be further analyzed by synthesis with survey data.

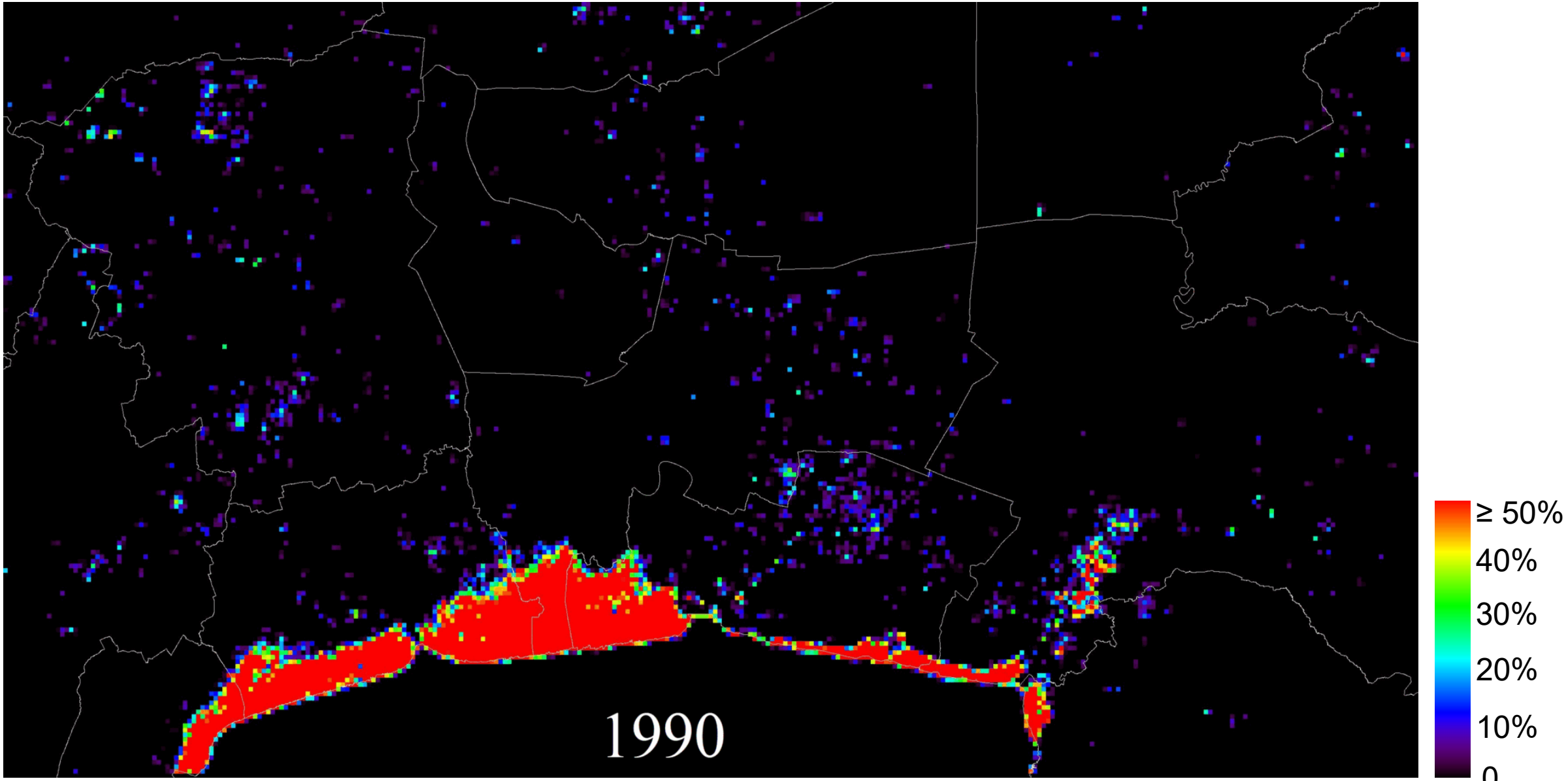
Project next steps

- Synthesize Thailand survey data with LCLUC maps and pond extraction results
- Collate survey data in India and previously-collected survey data in Myanmar and Bangladesh
- Extract ponds and generate LCLUC maps in India, Myanmar, and Bangladesh
- Synthesize survey data with remote sensing results to address the hypotheses
- Write amazing papers

Backup slides

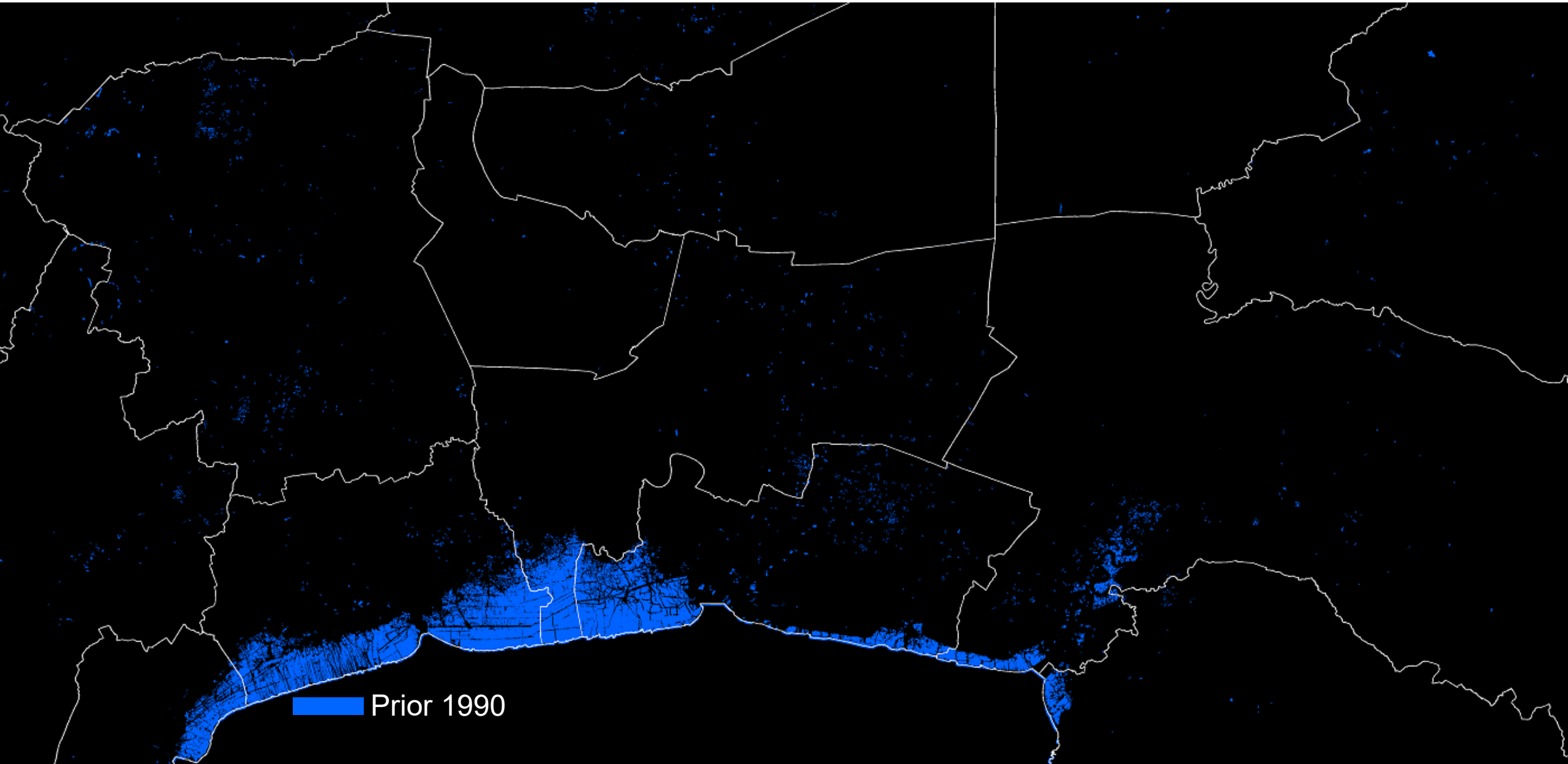
Aquaculture area in Central Thailand

Aquaculture area percentage in 1.5 km x 1.5 km gridcells

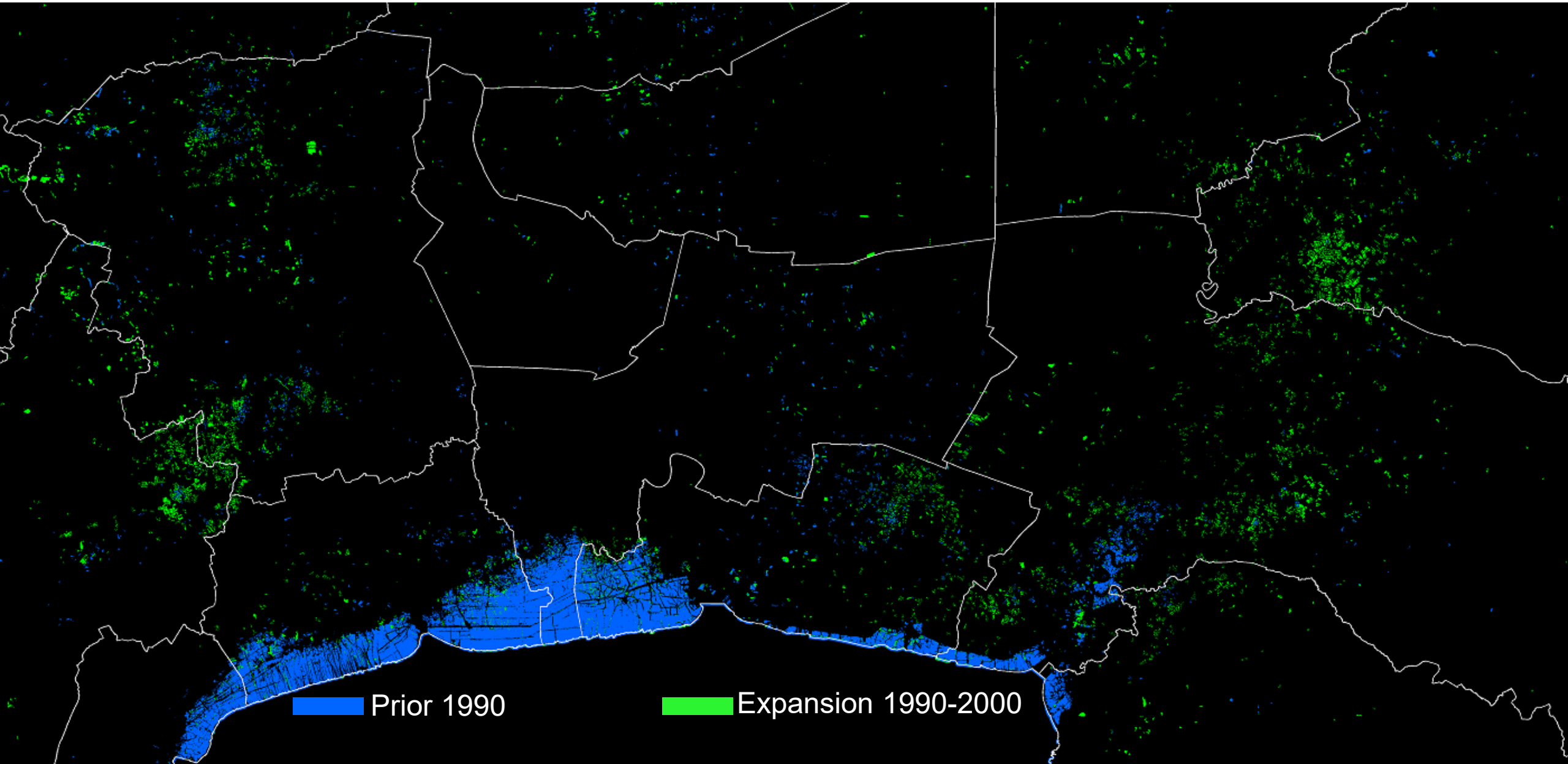


Only look at expansion

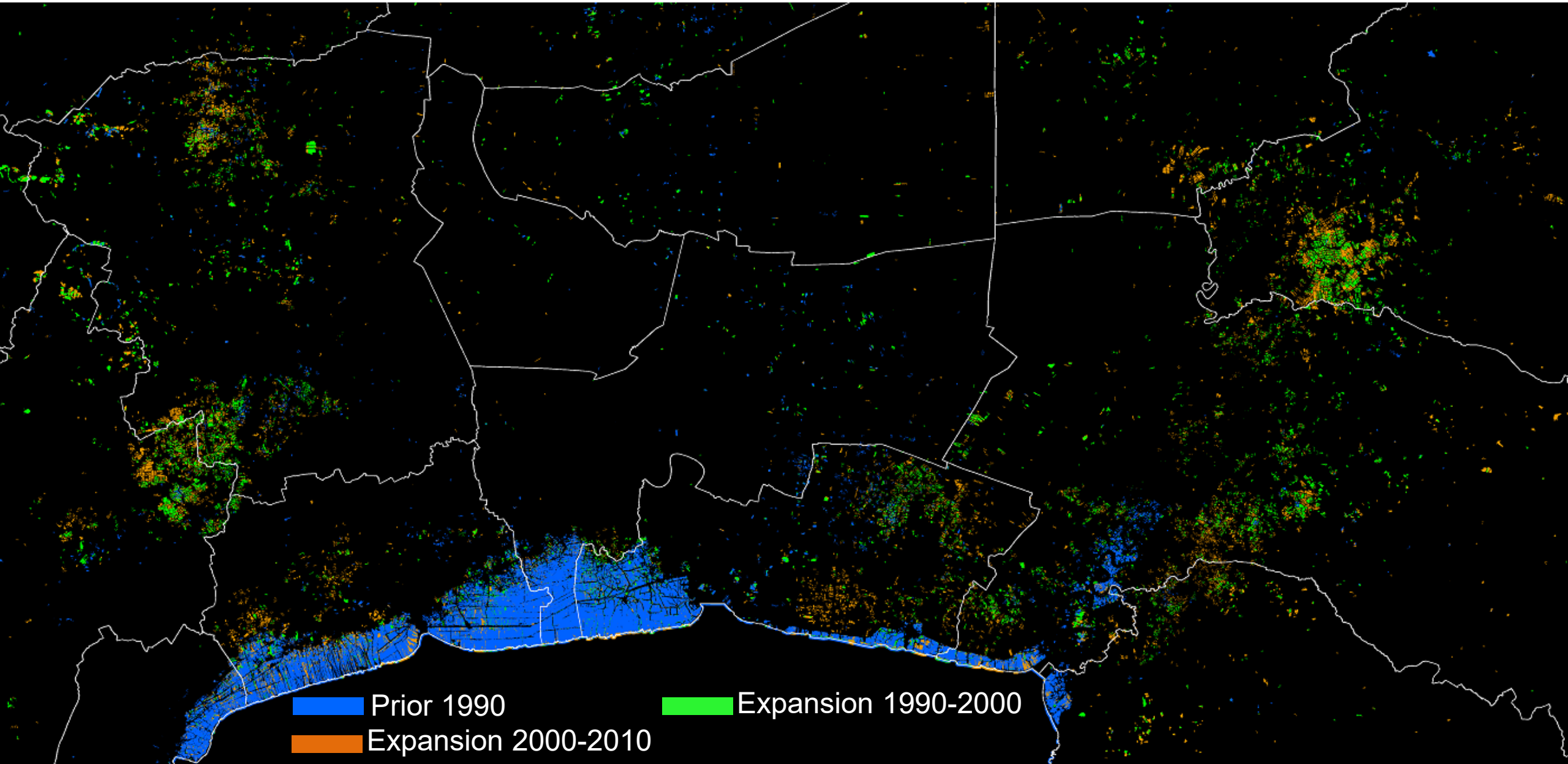
Aquaculture expansion in Central Thailand



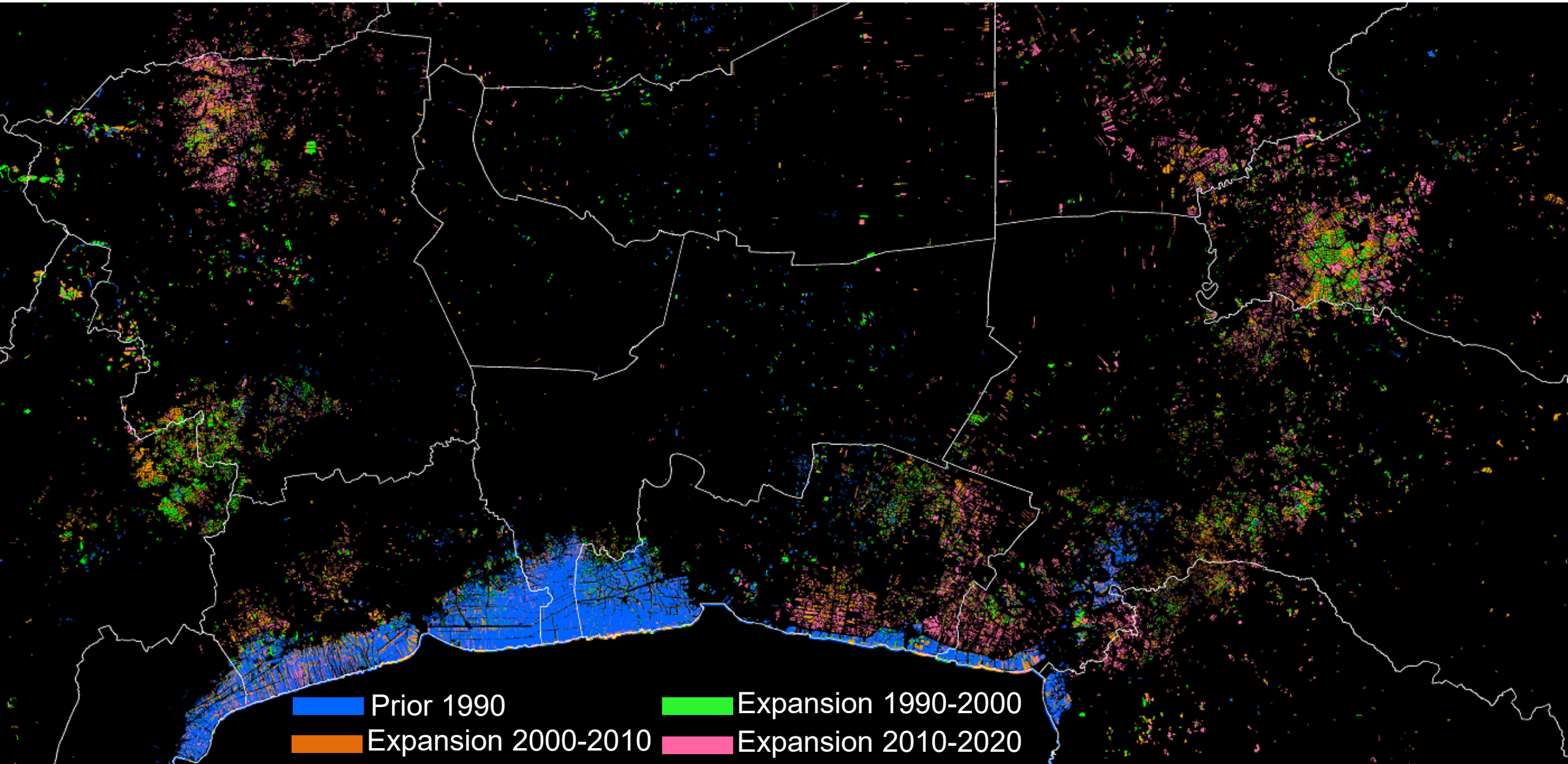
Aquaculture expansion in Central Thailand



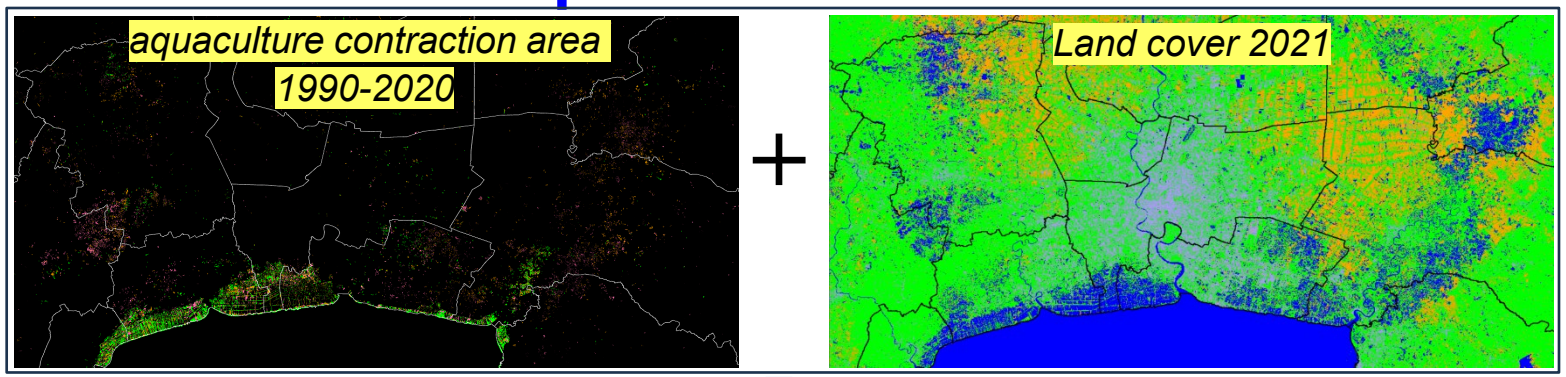
Aquaculture expansion in Central Thailand



Aquaculture expansion in Central Thailand



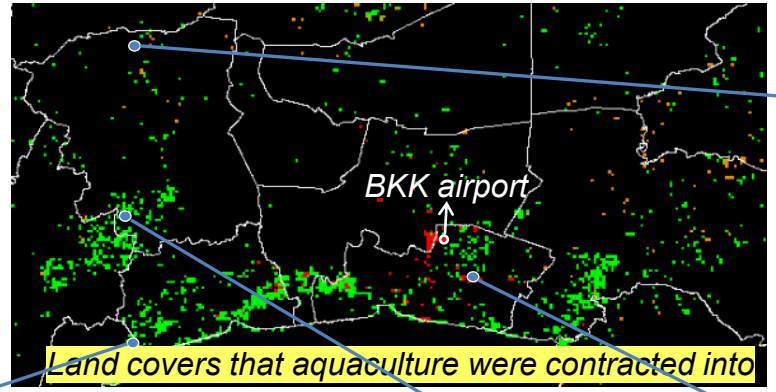
What was aquaculture contracted into?

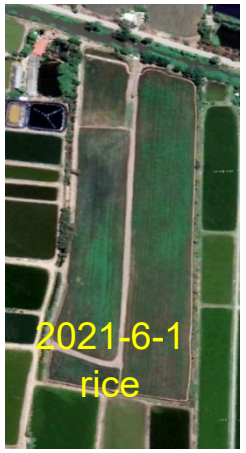


Rice (14%)

Urban (15%)

Other Vegetation (71%)





(Yan et al. 2024)