Aquaculture and Coastal Habitats Report No. 6

# Phase 3 Extension to the Mapping of Tropical Pond Aquaculture, Mangroves and Coastal Wetlands

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## Introduction

Phase 3 of the mapping of tropical pond aquaculture, mangroves and other coastal wetlands included extensions in geography and time. New countries added included Indonesia, Bangladesh, India and Ecuador, adding to the countries of Vietnam, Cambodia, Thailand and Myanmar mapped in earlier phases. The baseline year of 2014 was also augmented to include 1999 and 2018 for all areas. Efficiencies in the mapping procedure also allowed the countries of Malaysia and Sri Lanka to be added, again for 1999, 2014 and 2018.

Another change that was made from previous phases is that the land cover categories were collapsed to a more focused group:

- Mangroves
- Other Coastal Wetlands
- Pond Aquaculture
- Open Water
- Other
- Missing

The rationale for the more focused categories was to speed up the mapping program. In previous phases, it was found that the major effort was in mapping cropland and settlements – categories that were not essential to the goals of the mapping. In this categorization, other coastal wetlands include any non-mangrove wetland, fresh or brackish, that occurs within the defined coastal zone. Pond aquaculture is understood to mean brackish pond aquaculture. Since pond salinity cannot be sensed, this is defined primarily by the definition of the coastal zone. However, where good ancillary information exists that significant freshwater ponds are present, they are separately delineated (such as in Myanmar) and are not included in the statistics discussed here. The other category includes all other types of land cover – primarily cropland, non-mangrove forests and settlements.

In the following sections, a focus is placed on the status of pond aquaculture and mangroves in all 10 countries mapped to date. This includes 1999, 2014 and 2018 and the changes between them. The analysis also includes areas mapped in earlier phases, as some areas from 2014 have been remapped based on the experience of adding new maps for 1999 and 2018. Tables are reported at the national level, but the discussion includes consideration of the distribution at the first administrative divisions (e.g., provinces or states) and relies upon the tables provided in the Supplementary Materials as evidence. Maps and graphs at both the national and provincial levels can also be accessed at

www.clarklabs.org/aquaculture. Discussion about the methodology and an accuracy assessment can be found at the end of the report, including supplementary data with detailed statistics.

## The Status of Pond Aquaculture and Mangroves: National Level Overview

Table 1 presents the areal statistics for pond aquaculture by country for 1999, 2014 and 2018, along with net change between those dates (in $km^2$) and rates of change (in $km^2$/yr). The entries are sorted in descending order of pond area in 2018.

The distribution of pond area by country follows a logarithmic progression. Vietnam and Indonesia stand out as having the largest coverage of pond aquaculture with over 8000 $km^2$ each, followed by India[1] with about half as much, and then Thailand, Bangladesh and Ecuador with half as much again. Then dropping about 10-fold, Malaysia, Myanmar, Sri Lanka and Cambodia each have less than 200 $km^2$.

Looking at the rates of change, Vietnam and Indonesia had their greatest increases from 1999-2014. Growth rates were 352.8 $km^2$/yr and 165.5 $km^2$/yr respectively. However, these rates slowed considerably between 2014-2018. Vietnam experienced a small decrease in pond area during this period, while Indonesia slowed to a still substantial rate of 62.3 $km^2$/yr. Bangladesh also slowed by a factor of three over this period, from 24.8 $km^2$/yr between 1999-2014 to 7.3 $km^2$/yr between 2014-2018.

In contrast, India and Ecuador saw a four-fold increase in the rate of conversion from the early period (1999-2014) to the later period (2014-2018). India's rate of conversion changed from 73.6 $km^2$/yr to 226.4 $km^2$/yr, making it the location that is currently experiencing the most rapid rate of pond aquaculture introduction of the 10 countries examined. Ecuador changed from 7.7 $km^2$/yr to 33.6 $km^2$/yr to become the third highest rate of introduction after India and Indonesia.

**Table 1: Area statistics for pond aquaculture and change, by country, for 1999, 2014 and 2018.**

| Country | Pond 1999 ($km^2$) | Pond 2014 ($km^2$) | Pond 2018 ($km^2$) | Net Change 1999 – 2014 ($km^2$) | Net Change 2014 – 2018 ($km^2$) | Net Change 1999 – 2018 ($km^2$) | Rate of Change 1999 – 2014 ($km^2$/yr) | Rate of Change 2014 – 2018 ($km^2$/yr) | Rate of Change 1999 – 2018 ($km^2$/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Vietnam | 3680.3 | 8973.0 | 8938.7 | 5292.7 | -34.2 | 5258.5 | 352.8 | -8.6 | 276.8 |
| Indonesia | 5719.9 | 8203.2 | 8452.5 | 2483.2 | 249.4 | 2732.6 | 165.5 | 62.3 | 143.8 |
| India | 2572.4 | 3676.9 | 4582.4 | 1104.5 | 905.5 | 2009.9 | 73.6 | 226.4 | 105.8 |
| Thailand | 2652.1 | 2559.4 | 2588.6 | -92.7 | 29.3 | -63.5 | -6.2 | 7.3 | -3.3 |
| Bangladesh | 1774.3 | 2146.2 | 2175.3 | 371.9 | 29.1 | 401.0 | 24.8 | 7.3 | 21.1 |
| Ecuador | 1571.3 | 1686.5 | 1820.8 | 115.2 | 134.3 | 249.5 | 7.7 | 33.6 | 13.1 |
| Malaysia | 92.9 | 175.8 | 181.0 | 82.9 | 5.2 | 88.1 | 5.5 | 1.3 | 4.6 |
| Myanmar | 194.5 | 161.2 | 170.6 | -33.4 | 9.4 | -23.9 | -2.2 | 2.4 | -1.3 |
| Sri Lanka | 56.2 | 58.8 | 59.8 | 2.6 | 0.9 | 3.5 | 0.2 | 0.2 | 0.2 |
| Cambodia | 5.3 | 16.6 | 16.4 | 11.3 | -0.2 | 11.0 | 0.8 | -0.1 | 0.6 |

[1] The figures for India are provisional. The outbreak of Covid-19 interrupted field work planned to determine the proportion and location of freshwater ponds in Andhra Pradesh. In this report, all ponds in the coastal zone of India are assumed to be brackish water ponds.

Table 2 presents the areal statistics for mangroves by country for 1999, 2014 and 2018, along with net change between those dates (in $km^2$) and rates of change (in $km^2$/yr). The entries are sorted in descending order of mangrove area in 2018.

The largest national extent of mangroves is in Indonesia, with 31,157.2 $km^2$ – almost five times as much as any other country analyzed. After that, the distribution declines linearly from Myanmar and Malaysia with over 6000 $km^2$ each to Cambodia and Sri Lanka with less than 1000 $km^2$ each.

Looking over the whole period from 1999-2018, three countries experienced a decline in stocks – Indonesia which saw a decline of 82.9 $km^2$/yr, Myanmar with a decline of 43.5 $km^2$/yr and Malaysia with a decline of 15.2 $km^2$/yr. For Myanmar, the decline happened primarily from 1999-2014 with the rate changing from a loss of 58.1 $km^2$/yr from 1999-2014 to a gain of 11.4 $km^2$/yr from 2014-2018. In contrast, Indonesia and Malaysia both saw an increase in the rate of mangrove loss from 73.9 to 116.5 $km^2$/yr in Indonesia and 13.3 to 22.5 $km^2$/yr in Malaysia between the 1999-2014 and 2014-2018 periods. All other countries experienced a net increase in mangroves, most notably India and Vietnam.

**Table 2: Area statistics for mangrove and change, by country, for 1999, 2014 and 2018.**

| Country | Mangrove 1999 ($km^2$) | Mangrove 2014 ($km^2$) | Mangrove 2018 ($km^2$) | Net Change 1999 – 2014 ($km^2$) | Net Change 2014 – 2018 ($km^2$) | Net Change 1999 – 2018 ($km^2$) | Rate of Change 1999 – 2014 ($km^2$/yr) | Rate of Change 2014 – 2018 ($km^2$/yr) | Rate of Change 1999 – 2018 ($km^2$/yr) |
|---|---|---|---|---|---|---|---|---|---|
| Indonesia | 32731.7 | 31623.3 | 31157.2 | -1108.4 | -466.1 | -1574.5 | -73.9 | -116.5 | -82.9 |
| Myanmar | 7259.2 | 6387.1 | 6432.9 | -872.1 | 45.7 | -826.3 | -58.1 | 11.4 | -43.5 |
| Malaysia | 6320.8 | 6121.0 | 6031.2 | -199.8 | -89.8 | -289.7 | -13.3 | -22.5 | -15.2 |
| Bangladesh | 4490.8 | 4521.7 | 4526.2 | 31.0 | 4.5 | 35.4 | 2.1 | 1.1 | 1.9 |
| India | 3349.8 | 3843.3 | 3892.6 | 493.4 | 49.3 | 542.8 | 32.9 | 12.3 | 28.6 |
| Thailand | 2386.4 | 2617.1 | 2627.5 | 230.8 | 10.4 | 241.1 | 15.4 | 2.6 | 12.7 |
| Vietnam | 1735.8 | 1809.5 | 2007.5 | 73.7 | 198.0 | 271.7 | 4.9 | 49.5 | 14.3 |
| Ecuador | 1485.2 | 1507.9 | 1512.0 | 22.7 | 4.1 | 26.8 | 1.5 | 1.0 | 1.4 |
| Cambodia | 505.7 | 481.0 | 479.3 | -24.8 | -1.7 | -26.4 | -1.7 | -0.4 | -1.4 |
| Sri Lanka | 132.8 | 145.9 | 144.9 | 13.1 | -1.0 | 12.1 | 0.9 | -0.2 | 0.6 |

Tables 1 and 2 were rank ordered based on the absolute area of ponds and mangroves in 2018 respectively. The data can also be looked at in other ways. Table 3 sorts the countries based on Pond area in 2018 relative to the land area of each country's coastal zone[2]. From this, Ecuador and Vietnam stand out with 12.96% and 10.34% of the coastal zone (land area) occupied by pond aquaculture in 2018.

[2] Areas classified as mangrove are treated as land and vary depending on factors such as new colonization and coastal erosion. For all comparisons to land area in the coastal zone, the zone as mapped in 2014 is used as the standard.

Table 4 rank orders the countries by the percent of the coastal zone (land area) gaining new pond from 1999-2018. From this perspective, Vietnam is very unusual, converting 6.08% of its coastal zone (land area) to pond between 1999-2018. This is three times higher than the next in rank order – India with 1.99%, followed by Ecuador (1.78%) and Bangladesh (1.02%). All remaining countries experienced less than 1%. Two countries, Myanmar and Thailand experienced a net loss of ponds over this period.

**Table 3: Countries rank ordered by percent of land area occupied by pond aquaculture in 2018 in the coastal zone.**

| Country | Pond Area 2018 ($km^2$) | Land Area of Coastal Zone ($km^2$) | Percent of Coastal Zone Land Area Occupied by Pond, 2018 |
|---|---|---|---|
| Ecuador | 1820.8 | 14046.1 | 12.96% |
| Vietnam | 8938.7 | 86476.0 | 10.34% |
| Thailand | 2588.6 | 41296.3 | 6.27% |
| Bangladesh | 2175.3 | 39484.5 | 5.51% |
| India | 4582.4 | 101234.4 | 4.53% |
| Indonesia | 8452.5 | 573288.2 | 1.47% |
| Sri Lanka | 59.8 | 12794.0 | 0.47% |
| Malaysia | 181.0 | 59869.3 | 0.30% |
| Myanmar | 170.6 | 70568.4 | 0.24% |
| Cambodia | 16.4 | 8174.4 | 0.20% |

**Table 4: Countries rank ordered by percent of coastal zone land area gaining new pond 1999-2018.**

| Country | Net Change in Pond Area 1999-2018 ($km^2$) | Land Area of Coastal Zone ($km^2$) | Percent of Coastal Zone Land Area Gaining New Pond, 1999-2018 |
|---|---|---|---|
| Vietnam | 5258.5 | 86476.0 | 6.08% |
| India | 2009.9 | 101234.4 | 1.99% |
| Ecuador | 249.5 | 14046.1 | 1.78% |
| Bangladesh | 401.0 | 39484.5 | 1.02% |
| Indonesia | 2732.6 | 573288.2 | 0.48% |
| Malaysia | 88.1 | 59869.3 | 0.15% |
| Cambodia | 11.0 | 8174.4 | 0.13% |
| Sri Lanka | 3.5 | 12794.0 | 0.03% |
| Myanmar | -23.9 | 70568.4 | -0.03% |
| Thailand | -63.5 | 41296.3 | -0.15% |

Table 5 rank orders the countries in terms of the percent of coastal zone land area occupied by mangrove in 2018. From this perspective, Bangladesh has the highest proportion of mangroves (11.46%), followed by Ecuador (10.76%) and Malaysia (10.7%). Indonesia stands out as having the fourth lowest percent (5.43%) despite having the largest area of mangroves on a national basis.

Table 6 presents the final rank ordering – this time by the percent of the coastal zone (land area) losing (signified with a negative sign) or gaining mangroves from 1999-2018. Here Myanmar stands out with the largest proportionate loss of mangrove (-1.17%). Malaysia (-4.8%), Cambodia (-0.32%) and Indonesia (-0.27%) are the other countries also experiencing a net loss. All other countries showed a net gain of mangroves, with India and Thailand experiencing over a half percent of gain (0.54% and 0.58% respectively).

**Table 5: Countries rank ordered by percent of coastal zone land area occupied by mangrove in 2018.**

| Country | Mangrove Area 2018 ($km^2$) | Land Area of Coastal Zone ($km^2$) | Percent of Coastal Zone Land Area Occupied by Mangroves, 2018 |
|---|---|---|---|
| Bangladesh | 4526.2 | 39484.5 | 11.46% |
| Ecuador | 1512.0 | 14046.1 | 10.76% |
| Malaysia | 6031.2 | 59869.3 | 10.07% |
| Myanmar | 6432.9 | 70568.4 | 9.12% |
| Thailand | 2627.5 | 41296.3 | 6.36% |
| Cambodia | 479.3 | 8174.4 | 5.86% |
| Indonesia | 31157.2 | 573288.2 | 5.43% |
| India | 3892.6 | 101234.4 | 3.85% |
| Vietnam | 2007.5 | 86476.0 | 2.32% |
| Sri Lanka | 144.9 | 12794.0 | 1.13% |

**Table 6: Countries rank ordered by percent of coastal zone land area losing (-) or gaining mangrove 1999-2018.**

| Country | Net Change in Mangrove Area 1999-2018 ($km^2$) | Land Area of Coastal Zone ($km^2$) | Percent of Coastal Zone Land Area Losing Mangrove, 1999-2018 |
|---|---|---|---|
| Myanmar | -826.3 | 70568.4 | -1.17% |
| Malaysia | -289.7 | 59869.3 | -0.48% |
| Cambodia | -26.4 | 8174.4 | -0.32% |
| Indonesia | -1574.5 | 573288.2 | -0.27% |
| Bangladesh | 35.4 | 39484.5 | 0.09% |
| Sri Lanka | 12.1 | 12794.0 | 0.09% |
| Ecuador | 26.8 | 14046.1 | 0.19% |
| Vietnam | 271.7 | 86476.0 | 0.31% |
| India | 542.8 | 101234.4 | 0.54% |
| Thailand | 241.1 | 41296.3 | 0.58% |

## Change Analysis: Vietnam

As noted in Table 1, Vietnam has the largest quantity of pond aquaculture of all countries examined (8938.7 $km^2$ in 2018). In addition, it has the second highest density of pond aquaculture in the coastal zone (10.34%) after Ecuador (Table 3). Vietnam experienced a very large increase in pond aquaculture from 1999-2014 which followed with a slight loss from 2014-2018. Meanwhile, mangroves experienced a net gain, particularly from 2014-2018. Table 7 presents the primary land cover transitions from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

**Table 7: Primary land transitions in Vietnam by area (in $km^2$) and rates of change (in $km^2$/yr)**

| Category | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 1087.9 | 1561.6 | 1046.6 | - | - | - |
| Mangrove -> Pond | 532.7 | 185.1 | 506.8 | 35.5 | 46.3 | 26.7 |
| Mangrove -> Other | 99.8 | 24.9 | 97.4 | 6.7 | 6.2 | 5.1 |
| Mangrove -> Water | 62.5 | 35.6 | 85.7 | 4.2 | 8.9 | 4.5 |
| Pond Persistence | 2953.1 | 8522.3 | 2837.8 | - | - | - |
| Pond -> Mangrove | 297.5 | 392.5 | 386.0 | 19.8 | 98.1 | 20.3 |
| Pond -> Other | 371.4 | 42.7 | 384.8 | 24.8 | 10.7 | 20.3 |
| Pond -> Water | 69.5 | 4.5 | 66.2 | 4.6 | 1.1 | 3.5 |
| Other -> Pond | 5273.4 | 209.7 | 5351.1 | 351.6 | 52.4 | 281.6 |
| Wetland Persistence | 283.7 | 195.1 | 100.7 | - | - | - |
| Wetland -> Pond | 18.6 | 7.5 | 24.9 | 1.2 | 1.9 | 1.3 |
| Wetland -> Other | 28.1 | 285.2 | 205.6 | 1.9 | 71.3 | 10.8 |
| Water -> Mangrove | 151.3 | 38.1 | 151.4 | 10.1 | 9.5 | 8.0 |
| Water -> Pond | 128.0 | 9.8 | 134.9 | 8.5 | 2.4 | 7.1 |

The large increase in pond aquaculture from 1999-2014 came primarily from the other land cover category (mostly cropland) – 5273.4 $km^2$, almost entirely in the Mekong Delta (particularly Cau Mau, 1873.6 $km^2$, Kien Giang, 1182.1 $km^2$ and Bac Lieu, 938.1 $km^2$). This is associated with a government decree in 2000 that promoted the large-scale conversion of low-yield rice cultivation to shrimp farming (Can et al., 2007). An additional 532.7 $km^2$ came from mangroves, predominantly from Cau Mau (238.0 $km^2$), Tra Vinh (126.6 $km^2$) and Ben Tre (49.0 $km^2$). Pond losses were small compared to pond gains and were fairly evenly divided between other lands and mangroves.

In the later period (2014-2018), growth in pond aquaculture was fairly evenly distributed between contributions from other lands (209.7 $km^2$) and mangroves (185.1 $km^2$). This mangrove conversion was again primarily from Cau Mau (59.2 $km^2$), Tra Vinh (37.8 $km^2$) and Ben Tre (25.1 $km^2$). Meanwhile, pond loss experienced a huge change with the rate of transition from pond to mangrove jumping from 19.8 $km^2$/yr between 1999-2014 to 98.1 $km^2$/yr from 2014-2018. This is almost entirely in Cau Mau (341.3 $km^2$ from 2014-2018) associated with the government's efforts to establish integrated mangrove shrimp farming (Olivier et al., 2015). It could thus be argued that this is not so much a case of pond loss as it is a change in the character of the ponds.

Over the entire study period, mangrove loss was primarily associated with pond aquaculture (26.7 $km^2$/yr), with smaller amounts being associated with losses to other (5.1 $km^2$/yr) and water (4.5 $km^2$/yr).

The latter is particularly associated with mangrove erosion along the south coast of Cau Mau. Note that the rate of mangrove loss from 1999-2018 was lower than either 1999-2014 or 2014-2018. This may seem counterintuitive, but relates to the relative exchange between ponds and mangroves (e.g., mangrove gain from ponds) in the interim. Mangrove gain comes primarily from pond (at an average of 20.3 $km^2$ per year), but also from water (8.0 $km^2$/yr), primarily as a result of new mangrove colonization. This is particularly evident in north and northwest coastal areas of Cau Mau where it would appear that sediment deposition is facilitating mangrove growth.

## Change Analysis: Indonesia

Indonesia has the second highest quantity of pond aquaculture (8452.5 $km^2$ in 2018) after Vietnam (Table 1) and the highest reserves of mangroves (31157.2 $km^2$ in 2018 – Table 2). However, the coastal zone of Indonesia is huge, and the density of pond aquaculture and mangroves within it is moderate (Tables 3 and 4).

Table 8 presents the primary land cover transitions in Indonesia from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

**Table 8: Primary land transitions in Indonesia by area (in $km^2$) and rates of change (in $km^2$/yr)**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 29597.4 | 31034.3 | 29051.1 | - | - | - |
| Mangrove -> Pond | 1831.7 | 297.4 | 2024.5 | 122.1 | 74.3 | 106.6 |
| Mangrove -> Other | 888.3 | 332.4 | 1209.0 | 59.2 | 83.1 | 63.6 |
| Mangrove -> Water | 203.2 | 33.3 | 227.9 | 13.5 | 8.3 | 12.0 |
| Pond Persistence | 5013.9 | 8254.9 | 5007.5 | - | - | - |
| Pond -> Mangrove | 454.5 | 86.1 | 443.4 | 30.3 | 21.5 | 23.3 |
| Pond -> Other | 318.3 | 32.5 | 336.5 | 21.2 | 8.1 | 17.7 |
| Pond -> Water | 110.7 | 13.5 | 115.4 | 7.4 | 3.4 | 6.1 |
| Other -> Pond | 1342.4 | 76.8 | 1397.3 | 89.5 | 19.2 | 73.5 |
| Wetland Persistence | 30016.2 | 32037.7 | 28316.5 | - | - | - |
| Wetland -> Pond | 43.2 | 4.7 | 45.4 | 2.9 | 1.2 | 2.4 |
| Wetland -> Other | 12469.0 | 184.7 | 13025.3 | 831.3 | 46.2 | 685.5 |
| Water -> Mangrove | 349.9 | 92.1 | 413.0 | 23.3 | 23.0 | 21.7 |
| Water -> Pond | 44.5 | 8.8 | 53.2 | 3.0 | 2.2 | 2.8 |

Unlike Vietnam, the primary conversion to pond aquaculture was from mangroves. Indeed, pond aquaculture is the primary contributor to Indonesia's net loss of mangroves. Over the entire period (1999-2018) 106.6 $km^2$/yr were converted from mangrove to pond aquaculture and 73.5 $km^2$ from other to pond aquaculture. Almost 80% of the conversion from mangrove to pond over this period came from Kalimantan – primarily from Kalimantan Utara (808.1 $km^2$) and Kalimantan Timur (601.5 $km^2$). This is the highest rate of conversion from mangroves to pond encountered in any of the countries examined. Another 13.5% of the mangrove to pond conversion came from Sulawesi, primarily Sulawesi Selatan (93.8 $km^2$), Sulawesi Tenggara (69.2 $km^2$) and Gorontalo (49.6 $km^2$. Conversion from other to pond

aquaculture over the 1999-2018 period occurred fairly evenly across Kalimantan (31%), Sulawesi (26%), Sumatra (22%) and Java (19%).

A distinctive feature of Indonesia is the amount of non-mangrove coastal wetlands. Their area (32835 $km^2$ in 2018) is similar to that of mangroves These are almost exclusively peatlands. From 1999-2014 there were huge losses of wetlands to other (12469.0 $km^2$) representing an annual rate of 831.3 $km^2$/yr. From 2014-2018, however, the rate had slowed to 46.2 $km^2$/yr. Between 1999-2018, 68% of this conversion happened in Sumatra and 26% in Kalimantan.

## Change Analysis: India

India has the third largest area of pond aquaculture (4582.4 $km^2$ in 2018) after Vietnam and Indonesia, and the highest rate of growth in the recent period, 2014-2018 (226.4 $km^2$/yr). However, it should be noted that these figures are provisional. Travel restrictions because of Covid-19 prevented field verification in Andhra Pradesh to investigate the division between brackish and freshwater ponds. Figures for that state may change after travel and verification takes place.

Table 9 presents the primary land cover transitions in India from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

**Table 9: Primary land transitions in India by area (in km2) and rates of change (in km2/yr)**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 3212.7 | 3802.0 | 3199.1 | - | - | - |
| Mangrove -> Pond | 10.1 | 4.6 | 12.2 | 0.7 | 1.1 | 0.6 |
| Mangrove -> Other | 48.8 | 21.6 | 69.0 | 3.3 | 5.4 | 3.6 |
| Mangrove -> Water | 77.3 | 15.0 | 69.5 | 5.2 | 3.7 | 3.7 |
| Pond Persistence | 2274.3 | 3630.5 | 2311.5 | - | - | - |
| Pond -> Mangrove | 25.8 | 6.5 | 32.5 | 1.7 | 1.6 | 1.7 |
| Pond -> Other | 267.8 | 36.5 | 223.4 | 17.9 | 9.1 | 11.8 |
| Pond -> Water | 3.8 | 3.2 | 4.5 | 0.3 | 0.8 | 0.2 |
| Other -> Pond | 1335.2 | 944.0 | 2183.1 | 89.0 | 236.0 | 114.9 |
| Wetland Persistence | 153.8 | 183.0 | 146.0 | - | - | - |
| Wetland -> Pond | 1.4 | 2.1 | 5.5 | 0.1 | 0.5 | 0.3 |
| Wetland -> Other | 11.2 | 0.6 | 8.7 | 0.7 | 0.2 | 0.5 |
| Water -> Mangrove | 118.3 | 17.3 | 131.6 | 7.9 | 4.3 | 6.9 |
| Water -> Pond | 7.7 | 1.1 | 12.2 | 0.5 | 0.3 | 0.6 |

A notable feature about India is that while there is considerable growth of pond aquaculture, very little of it comes from mangroves (just 12.2 $km^2$ from 1999 to 2018). Almost all of it comes from other lands (2183.1 $km^2$ from 1999-2014). Geographically, almost half (1059.93 $km^2$) comes from Andhra Pradesh while an additional quarter (574.59 $km^2$) comes from West Bengal. Gujarat and Orissa each account for about 10% (201.23 and 250.72 $km^2$ respectively) with just over 3% in Tamil Nadu (69.41 $km^2$).

## Change Analysis: Thailand

Table 10 presents the primary land cover transitions in Thailand from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

Conversion of ponds to mangrove remained quite consistent over all time periods examined. Over 1999-2018, the conversion rate was only 1.2 $km^2$/yr. This was countered by a conversion rate of pond back to mangrove of 8.7 $km^2$/yr, contributing to a net loss of ponds of 3.3 $km^2$/yr (Table 1). There was a higher rate of conversion of other lands to ponds over this period (35.9 $km^2$/yr). But again, this was balanced by a conversion rate of 30.9 $km^2$/yr from ponds back to other lands. It would appear, then, that the areal extent of pond aquaculture is quite stable in Thailand at this time, and that protection of mangroves is largely being maintained. As of 2018, over 50% of pond aquaculture, by area, occurs in just six provinces: Chachoengsao (13%), Samut Prakan (10%), Nakhon Si Thammarat (8%), Chanthaburi (8%), Samut Sakhon (7%) and Nakhon Pathom (5%).

With regards to mangroves, Thailand has experienced a modest net gain at a rate of 12.7 $km^2$/yr (Table 2) over the 1999-2018 period. Most of this comes from areas of previous pond aquaculture (8.7 $km^2$/yr), but a small amount also comes from areas previous covered by open water (1.5 $km^2$/yr).

**Table 10: Primary land transitions in Thailand by area (in $km^2$) and rates of change (in $km^2$/yr)**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 2295.1 | 2532.9 | 2265.2 | - | - | - |
| Mangrove -> Pond | 20.9 | 6.5 | 23.1 | 1.4 | 1.6 | 1.2 |
| Mangrove -> Other | 62.6 | 67.9 | 89.1 | 4.2 | 17.0 | 4.7 |
| Mangrove -> Water | 5.9 | 1.5 | 4.9 | 0.4 | 0.4 | 0.3 |
| Pond Persistence | 1888.6 | 2476.0 | 1879.4 | - | - | - |
| Pond -> Mangrove | 154.4 | 21.8 | 166.1 | 10.3 | 5.4 | 8.7 |
| Pond -> Other | 650.6 | 29.4 | 587.3 | 43.4 | 7.3 | 30.9 |
| Pond -> Water | 10.0 | 0.2 | 9.1 | 0.7 | 0.1 | 0.5 |
| Other -> Pond | 646.7 | 75.1 | 682.4 | 43.1 | 18.8 | 35.9 |
| Wetland Persistence | 534.7 | 520.4 | 518.6 | - | - | - |
| Wetland -> Pond | 2.5 | 0.8 | 3.1 | 0.2 | 0.2 | 0.2 |
| Wetland -> Other | 69.7 | 9.8 | 84.6 | 4.6 | 2.4 | 4.5 |
| Water -> Mangrove | 21.1 | 8.8 | 28.1 | 1.4 | 2.2 | 1.5 |
| Water -> Pond | 0.4 | 0.4 | 0.4 | 0.0 | 0.1 | 0.0 |

## Change Analysis: Bangladesh

Table 11 presents the primary land cover transitions in Bangladesh from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

Pond aquaculture continues to grow in Bangladesh, at a net rate of 21.1 $km^2$/yr over the 1999-2018 period (Table 1). However, this growth is coming almost entirely from other lands, with virtually no conversion from ponds (0.7 $km^2$ from 1999-2018). In 2018, 90% of pond aquaculture occurred in Kulna province, with 6%, 3% and 1% occurring in Chittagong, Dhaka and Barisal provinces respectively.

Meanwhile mangroves in Bangladesh experienced a slight increase of 1.9 $km^2$/yr over this period, primarily from growth in open water areas exceeding losses.

**Table 11: Primary land transitions in Bangladesh by area (in $km^2$) and rates of change (in $km^2$/yr)**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 4389.8 | 4513.2 | 4383.4 | - | - | - |
| Mangrove -> Pond | 0.2 | 0.5 | 0.7 | 0.0 | 0.1 | 0.0 |
| Mangrove -> Other | 46.4 | 0.1 | 43.5 | 3.1 | 0.0 | 2.3 |
| Mangrove -> Water | 54.4 | 8.1 | 63.2 | 3.6 | 2.0 | 3.3 |
| Pond Persistence | 1431.5 | 2099.2 | 1424.8 | - | - | - |
| Pond -> Mangrove | 0.4 | 0.5 | 0.5 | 0.0 | 0.1 | 0.0 |
| Pond -> Other | 339.1 | 45.8 | 342.7 | 22.6 | 11.5 | 18.0 |
| Pond -> Water | 3.2 | 0.7 | 6.3 | 0.2 | 0.2 | 0.3 |
| Other -> Pond | 708.4 | 75.2 | 742.7 | 47.2 | 18.8 | 39.1 |
| Wetland Persistence | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wetland -> Pond | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wetland -> Other | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Water -> Mangrove | 99.9 | 11.8 | 107.9 | 6.7 | 2.9 | 5.7 |
| Water -> Pond | 5.8 | 0.4 | 6.9 | 0.4 | 0.1 | 0.4 |

## Change Analysis: Ecuador

Table 12 presents the primary land cover transitions in Ecuador from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

Ecuador has experienced a net increase in pond aquaculture at a rate of 13.1 $km^2$/yr (Table 1) over the period 1999-2018. However, the recent period (2014-2018) has seen this accelerate to 33.6 $km^2$/yr. From the data in Table 8, it is clear that this is primarily coming from other lands. Mangrove conversion for aquaculture has only been 0.2 $km^2$/yr over the larger study period (1999-2018), although the recent period of 2014-2018 has experienced a rate of 3.8 $km^2$/yr. Overall, however, mangrove has experienced a net increase in area, primarily because of natural expansion into open water.

As of 2018, 61% of Ecuador's pond aquaculture occurs in Guayas province, followed by 21% in El Oro. Pond area in Manabi, Esperaldas and Santa Elena is 9%, 6% and 2% of all pond area.

**Table 12: Primary land transitions in Ecuador by area (in km²) and rates of change (in km²/yr)**

| Category | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 1452.1 | 1443.8 | 1503.0 | - | - | - |
| Mangrove -> Pond | 15.6 | 15.2 | 4.3 | 1.0 | 3.8 | 0.2 |
| Mangrove -> Other | 9.5 | 12.0 | 0.0 | 0.6 | 3.0 | 0.0 |
| Mangrove -> Water | 7.8 | 8.1 | 0.6 | 0.5 | 2.0 | 0.0 |
| Pond Persistence | 1535.7 | 1508.5 | 1685.0 | - | - | - |
| Pond -> Mangrove | 17.1 | 17.6 | 1.3 | 1.1 | 4.4 | 0.1 |
| Pond -> Other | 17.4 | 20.5 | 0.1 | 1.2 | 5.1 | 0.0 |
| Pond -> Water | 1.1 | 1.6 | 0.1 | 0.1 | 0.4 | 0.0 |
| Other -> Pond | 228.6 | 286.9 | 130.0 | 15.2 | 71.7 | 6.8 |
| Wetland Persistence | 33.2 | 33.3 | 33.9 | - | - | - |
| Wetland -> Pond | 1.1 | 1.8 | 1.4 | 0.1 | 0.4 | 0.1 |
| Wetland -> Other | 4.5 | 2.8 | 1.5 | 0.3 | 0.7 | 0.1 |
| Water -> Mangrove | 31.8 | 34.4 | 7.8 | 2.1 | 8.6 | 0.4 |
| Water -> Pond | 0.4 | 0.8 | 0.1 | 0.0 | 0.2 | 0.0 |

## Change Analysis: Malaysia

Table 13 presents the primary land cover transitions in Malaysia from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods.

**Table 13: Primary land transitions in Malaysia by area (in km²) and rates of change (in km²/yr)**

| Category | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 5929.7 | 5983.6 | 5827.5 | - | - | - |
| Mangrove -> Pond | 50.8 | 3.0 | 53.1 | 3.4 | 0.8 | 2.8 |
| Mangrove -> Other | 297.4 | 126.5 | 389.2 | 19.8 | 31.6 | 20.5 |
| Mangrove -> Water | 42.9 | 7.8 | 50.4 | 2.9 | 2.0 | 2.7 |
| Pond Persistence | 75.2 | 171.3 | 73.8 | - | - | - |
| Pond -> Mangrove | 7.2 | 1.8 | 7.8 | 0.5 | 0.4 | 0.4 |
| Pond -> Other | 9.1 | 2.7 | 9.8 | 0.6 | 0.7 | 0.5 |
| Pond -> Water | 1.4 | 0.0 | 1.5 | 0.1 | 0.0 | 0.1 |
| Other -> Pond | 49.0 | 6.7 | 53.2 | 3.3 | 1.7 | 2.8 |
| Wetland Persistence | 2678.6 | 2562.5 | 2561.8 | - | - | - |
| Wetland -> Pond | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| Wetland -> Other | 2214.9 | 112.5 | 2322.6 | 147.7 | 28.1 | 122.2 |
| Water -> Mangrove | 75.6 | 10.5 | 84.6 | 5.0 | 2.6 | 4.5 |
| Water -> Pond | 0.6 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 |

Pond conversion in Malaysia is fairly modest, and is drawn from mangroves and other land areas at approximate the same rate (2.7 and 2.8 $km^2$/yr respectively between 1999-2018). The rate has noticeably slowed from 2014-2018, particularly from mangrove areas (0.8 $km^2$/yr – about a quarter of the rate from 1999-2014).

Conversion of mangroves from all sources is substantial in Malaysia. From 1999-2018, 15.2 $km^2$ have been lost each year. The largest source of this loss is the conversion to other lands. Between 1999-2014, the rate of loss has been 19.8 $km^2$/yr, but that increased by 60% from 2014-2018 with a loss rate of 31.6 $km^2$/yr. Overall, the rate of loss of mangroves in Malaysia from 2014-2018 is second only to Indonesia. Key areas for this loss of mangroves (including conversion to ponds) include Sarawak and Sabah on the island of Borneo, and Johor and Perak on the mainland.

## Change Analysis: Myanmar

Although Myanmar has substantial amounts of freshwater aquaculture (831.0 $km^2$ in 2018), in both absolute terms (Table 1), and as a proportion of the coastal zone (Table 3), Myanmar has comparatively little in the way of brackish pond aquaculture. In addition, from 1999-2018 it has been experiencing a net loss of brackish water ponds (Table 1). However, from 2014-2018 it has shown a slight turn around, with a growth of 2.4 $km^2$/yr. Meanwhile, it is second only to Indonesia in the absolute area of mangroves and in the rate of mangrove loss from 1999-2014 (Table 2). It has also experienced the highest rate of loss as a proportion of the coastal zone (1.17% -- Table 6) of any of the countries examined.

Table 14 presents the primary land cover transitions in Myanmar from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods. Note that all statistics related to ponds refer to brackish water ponds.

**Table 14: Primary land transitions in Myanmar by area (in $km^2$) and rates of change (in $km^2$/yr).**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 5908.3 | 5793.4 | 6192.4 | - | - | - |
| Mangrove -> Pond | 9.0 | 10.2 | 2.6 | 0.6 | 2.6 | 0.1 |
| Mangrove -> Other | 1292.5 | 1411.2 | 173.9 | 86.2 | 352.8 | 9.2 |
| Mangrove -> Water | 49.4 | 44.4 | 18.2 | 3.3 | 11.1 | 1.0 |
| Pond Persistence | 76.5 | 76.1 | 151.8 | - | - | - |
| Pond -> Mangrove | 13.0 | 18.2 | 6.9 | 0.9 | 4.6 | 0.4 |
| Pond -> Other | 80.5 | 98.6 | 2.4 | 5.4 | 24.6 | 0.1 |
| Pond -> Water | 24.6 | 1.7 | 0.0 | 1.6 | 0.4 | 0.0 |
| Other -> Pond | 70.2 | 78.4 | 15.4 | 4.7 | 19.6 | 0.8 |
| Wetland Persistence | 130.5 | 86.2 | 89.0 | - | - | - |
| Wetland -> Pond | 6.5 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 |
| Wetland -> Other | 0.4 | 4.5 | 1.6 | 0.0 | 1.1 | 0.1 |
| Water -> Mangrove | 123.6 | 173.1 | 31.0 | 8.2 | 43.3 | 1.6 |
| Water -> Pond | 5.4 | 5.9 | 0.8 | 0.4 | 1.5 | 0.0 |

The recent growth of pond aquaculture from 2014-2018 has come primarily from other lands (19.6 $km^2$/yr) rather than mangroves (only 2.6 $km^2$/yr). The growth of other lands has also been the primary source of mangrove loss, particularly from 2014-2018 (352.8 $km^2$/yr). Key provinces for pond development and loss of mangroves (all causes) have been Ayeyarwadi, Tanintharyi and Rakhine.

## Change Analysis: Sri Lanka

Sri Lanka had the second lowest area of pond aquaculture of the countries examined (59.8 $km^2$ in 2018 – Table 1) and the lowest absolute area of mangroves (144.9 km2 in 2018 – Table 2).

Table 15 presents the primary land cover transitions in Sri Lanka from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods. Pond growth is virtually entirely from conversion of other lands (0.3 $km^2$/yr from 1999-2018).

Mangroves have generally been slightly increasing in area in Sri Lanka (0.6 $km^2$/yr from 1999-2018 – Table 2) although there has been a decline of 0.2 $km^2$/yr from 2014-2018, primarily from other lands.

The primary areas for pond development and loss of mangroves (all sources) are Trincomalee, Puttalam and Batticaloa.

**Table 15: Primary land transitions in Sri Lanka by area (in $km^2$) and rates of change (in $km^2$/yr).**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 128.6 | 144.6 | 127.5 | - | - | - |
| Mangrove -> Pond | 0.2 | 0.1 | 0.3 | 0.0 | 0.0 | 0.0 |
| Mangrove -> Other | 3.9 | 0.6 | 3.9 | 0.3 | 0.2 | 0.2 |
| Mangrove -> Water | 0.1 | 0.6 | 1.1 | 0.0 | 0.1 | 0.1 |
| Pond Persistence | 51.5 | 58.7 | 52.1 | - | - | - |
| Pond -> Mangrove | 1.4 | 0.0 | 1.3 | 0.1 | 0.0 | 0.1 |
| Pond -> Other | 3.4 | 0.1 | 2.8 | 0.2 | 0.0 | 0.1 |
| Pond -> Water | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other -> Pond | 6.2 | 0.9 | 6.4 | 0.4 | 0.2 | 0.3 |
| Wetland Persistence | 356.2 | 485.8 | 355.7 | - | - | - |
| Wetland -> Pond | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Wetland -> Other | 297.2 | 0.6 | 297.8 | 19.8 | 0.2 | 15.7 |
| Water -> Mangrove | 6.1 | 0.0 | 6.2 | 0.4 | 0.0 | 0.3 |
| Water -> Pond | 0.9 | 0.0 | 0.9 | 0.1 | 0.0 | 0.0 |

## Change Analysis: Cambodia

From Table 1, it can be seen that Cambodia has the lowest amount of pond aquaculture of any of the countries examined (16.4 $km^2$ in 2018). It showed some gain of pond aquaculture between 1999 and 2014 (0.8 $km^2$/yr), but has then shown a net loss (-0.1 $km^2$/yr) since 2014.

Cambodia has a moderate density of mangroves (5.86% of the coastal zone land area in 2018 – Table 5). In absolute terms, its loss of mangroves is small, but relative to its proportion of the coastal zone, the rate is the third highest of the countries examined (-0.32% -- Table 6).

Table 16 presents the primary land cover transitions in Cambodia from 1999-2014, 2014-2018 and 1999-2018 as well as the rates of transition between periods. It is clear that any gains in pond aquaculture have come mostly from other lands and not mangroves to any appreciable extent. Similarly, mangrove loss is coming primarily from conversion to other lands. Koh Kong and Kampot are the primary areas experiencing these changes.

**Table 16: Primary land transitions in Cambodia by area (in km$^2$) and rates of change (in km$^2$/yr).**

| **Category** | 1999-2014 | 2014-2018 | 1999-2018 | Rate 99-14 | Rate 14-18 | Rate 99-18 |
|---|---|---|---|---|---|---|
| Mangrove Persistence | 464.0 | 478.0 | 461.6 | - | - | - |
| Mangrove -> Pond | 0.4 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 |
| Mangrove -> Other | 27.6 | 1.0 | 29.4 | 1.8 | 0.3 | 1.5 |
| Mangrove -> Water | 13.2 | 0.1 | 10.3 | 0.9 | 0.0 | 0.5 |
| Pond Persistence | 4.4 | 16.4 | 4.2 | - | - | - |
| Pond -> Mangrove | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Pond -> Other | 0.7 | 0.2 | 1.0 | 0.0 | 0.1 | 0.1 |
| Pond -> Water | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 |
| Other -> Pond | 10.4 | 0.0 | 10.3 | 0.7 | 0.0 | 0.5 |
| Wetland Persistence | 6.9 | 6.4 | 6.0 | - | - | - |
| Wetland -> Pond | 0.8 | 0.0 | 0.8 | 0.1 | 0.0 | 0.0 |
| Wetland -> Other | 1.0 | 0.0 | 1.0 | 0.1 | 0.0 | 0.1 |
| Water -> Mangrove | 6.4 | 0.8 | 7.1 | 0.4 | 0.2 | 0.4 |
| Water -> Pond | 0.7 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 |

## Impact of Pond Aquaculture on Mangroves

Given the change analysis for individual countries tabulated above, Table 17 rank orders the countries based on their rate of conversion from mangroves to pond aquaculture from 1999-2018. In addition, the table indicates the corresponding rates from 1999-2014 and 2014-2018. Note again that these rates are based on net changes which will be affected by factors such as growth of mangroves.

Indonesia stands out as having a rate four times higher than the next highest, Vietnam. In fact, its rate of conversion exceeds that of all other countries combined, by a factor of three. However, the rate of conversion has slowed somewhat from 2014-2018. Vietnam has the second highest rate of mangrove-to-pond conversion followed by Malaysia and Thailand. After that, the rate of conversion is very small – less than 1 km$^2$ per year.

**Table 17: Countries rank ordered by the rate of loss of mangroves to pond aquaculture 1999-2018**

| Country | Rate of Loss of Mangroves to Pond Aquaculture 1999-2014 ($km^2$/yr) | Rate of Loss of Mangroves to Pond Aquaculture 2014-2018 ($km^2$/y) | Rate of Loss of Mangroves to Pond Aquaculture 1999-2018 ($km^2$/yr) |
|---|---|---|---|
| Indonesia | 122.1 | 74.3 | 106.6 |
| Vietnam | 35.5 | 46.3 | 26.7 |
| Malaysia | 3.4 | 0.8 | 2.8 |
| Thailand | 1.4 | 1.6 | 1.2 |
| India | 0.7 | 1.1 | 0.6 |
| Ecuador | 1.0 | 3.8 | 0.2 |
| Myanmar | 0.6 | 2.6 | 0.1 |
| Bangladesh | 0.0 | 0.1 | 0.0 |
| Sri Lanka | 0.0 | 0.0 | 0.0 |
| Cambodia | 0.0 | 0.0 | 0.0 |

## Procedure

Because of the widened geographical scope of the project, a new map projection was developed. Previously, a special purpose Albers Conic Equal Area projection had been used because of its low distortion characteristics for Southeast Asia. However, to move to a global scope, a new projection was required.

The projection developed is based on a normal aspect Cylindrical Equal Area projection, as follows:

```
ref. system : Normal Aspect Cylindrical Equal Area
projection  : CylindricalEA
datum       : WGS84
delta WGS84 : 0 0 0
ellipsoid   : WGS 84
major s-ax  : 6378137.000
minor s-ax  : 6356752.314
origin long : 0
origin lat  : 0
origin X    : 0
origin Y    : 0
scale fac   : 1.0
units       : m
parameters  : 2
stand ln 1  : 10
stand ln 2  : -10
```

The standard parallels at 10 degrees north and south are intended to distribute angular error to be a minimum in the tropics. Because it is an equal area projection, there is no areal distortion. Thus, tabulated areas are correct.

The classification methodology applied was the same as that detailed in *Aquaculture and Coastal Habitats Report No. 5* (Eastman et al., 2018). Summarizing, mangroves, other coastal wetlands and water were mapped using a set of derived image bands that express vegetative productivity (Tasseled Cap Greenness), surface wetness (Tasseled Cap Wetness) and SRTM (Shuttle Radar Topography Mission) elevation with analyst-delineated samples for training and a Mahalanobis classifier. In contrast, pond aquaculture was mapped using a multi-layer perceptron neural network. Similar to other classes, analyst-delineated samples were used for training. However, the image

data used included Landsat bands 1-5 and 7, Tasseled Cap Greenness, Wetness and Brightness, and a large number of convolutions of these (3x3 and 5x5 mean filters and 3x3 slope (first derivative) images). SRTM elevation data were also used.

## Accuracy Assessment

As with earlier phases of the project, an accuracy assessment was conducted for the mappings of Indonesia, Bangladesh, India and Ecuador for 1999, 2014 and 2018. In addition, assessments were made for 2018 for Vietnam, Cambodia, Thailand and Myanmar, as these mappings were new.

The procedure used for accuracy assessment is the same as that described in *Aquaculture and Coastal Habitats Report No. 5* (Eastman et al., 2018). Summarizing, the sampling design was a two stage scheme that combines a *critical sampling* for selection of primary sampling units (Landsat scenes) and a stratified probability sampling for selection of the secondary sampling units (200 points in a near-shore zone and 100 points in the back zone). Three measures of accuracy are tabulated – User's, Producer's and Overall Accuracy. User's Accuracy expresses the relative frequency with which sample points on the map correctly map what is on the ground. Errors that reduce the User's Accuracy are known as errors of commission. Producer's Accuracy reverses this relationship and expresses the relative frequency with which points on the ground were correctly mapped. Errors that reduce the Producer's Accuracy are known as errors of omission. The Overall Accuracy is the average between the User's and Producer's Accuracy. Project standards were previously established as 85% for primary categories and 70% for secondary categories. In this phase, the primary categories were pond aquaculture, mangroves, and other coastal wetlands.

Table 18 shows the accuracy statistics for pond aquaculture in Indonesia, Bangladesh, India, and Ecuador for 1999, 2014 and 2018 and in Vietnam, Cambodia, Thailand and Myanmar in 2018. The median overall accuracy was 97.1%, well above the project standard, with a fairly even balance between User's and Producer's Accuracy (97.5% and 96.9% respectively).

Table 19 show the accuracy statistics for mangroves in Indonesia, Bangladesh, India, and Ecuador for 1999, 2014 and 2018 and in Vietnam, Cambodia, Thailand and Myanmar in 2018. The median overall accuracy was 97.2%, very similar to pond aquaculture. User's and Producer's Accuracy were 98.8% and 95.7% respectively, indicating that commission errors were lower that omission errors. However, all figures were well above the project standard.

The Other Coastal Wetland class is generally rare. The only country where the accuracy sampling picked enough points to statistically characterize (set to be a minimum of 5 points) was Indonesia. Table 20 presents the results. The median Overall Accuracy was 96.6% while the User's and Producer's accuracies were 97.3% and 89.3% respectively. As with ponds, errors of omission were thus more common than errors of omission. Again, all statistics exceeded the project standard.

**Table 18 : Accuracy Assessment for the Pond Aquaculture Class**

| Country | User's Accuracy | Producer's Accuracy | Overall Accuracy |
|---|---|---|---|
| Indonesia 1999 | 98.3% | 98.4% | 98.4% |
| Indonesia 2014 | 98.1% | 97.9% | 98.0% |
| Indonesia 2018 | 98.0% | 97.6% | 97.8% |
| Bangladesh 1999 | 92.1% | 92.1% | 92.1% |
| Bangladesh 2014 | 98.6% | 98.6% | 98.6% |
| Bangladesh 2018 | 100% | 100% | 100% |
| India 1999 | 98.2% | 90.3% | 94.2% |
| India 2014 | 97.3% | 95.3% | 96.3% |
| India 2018 | 92.5% | 95.4% | 94.0% |
| Ecuador 1999 | 98.8% | 100% | 99.4% |
| Ecuador 2014 | 94.8% | 96.9% | 95.8% |
| Ecuador 2018 | 97.5% | 96.7% | 97.1% |
| Vietnam 2018 | 96.7% | 98.7% | 97.7% |
| Cambodia 2018 | * | * | * |
| Thailand 2018 | 96.9% | 96.2% | 96.6% |
| Myanmar 2018 | 96.4% | 96.4% | 96.4% |
| **Median** | **97.5%** | **96.9%** | **97.1%** |

* Insufficient sample size to assess.

**Table 19 : Accuracy Assessment for the Mangrove Class**

| Country | User's Accuracy | Producer's Accuracy | Overall Accuracy |
|---|---|---|---|
| Indonesia 1999 | 99.3% | 96.6% | 98.0% |
| Indonesia 2014 | 98.9% | 94.4% | 96.6% |
| Indonesia 2018 | 96.8% | 95.7% | 96.2% |
| Bangladesh 1999 | 100% | 99.3% | 99.6% |
| Bangladesh 2014 | 98.6% | 98.6% | 98.6% |
| Bangladesh 2018 | 100% | 98.6% | 99.3% |
| India 1999 | 98.6% | 94.2% | 96.4% |
| India 2014 | 98.9% | 88.5% | 93.7% |
| India 2018 | 100% | 95.5% | 97.8% |
| Ecuador 1999 | 98.7% | 98.7% | 98.7% |
| Ecuador 2014 | 95.1% | 96.3% | 95.7% |
| Ecuador 2018 | 98.5% | 95.7% | 97.1% |
| Vietnam 2018 | 95.4% | 92.5% | 94.0% |
| Cambodia 2018 | 100% | 94.9% | 97.5% |
| Thailand 2018 | 97.7% | 96.6% | 97.2% |
| Myanmar 2018 | 100% | 92.3% | 96.2% |
| **Median** | **98.8%** | **95.7%** | **97.2%** |

**Table 20 : Accuracy Assessment for the Other Coastal Wetland Class**

| Country | User's Accuracy | Producer's Accuracy | Overall Accuracy |
|---|---|---|---|
| Indonesia 1999 | 94.7% | 92.7% | 98.0% |
| Indonesia 2014 | 97.3% | 86.6% | 96.6% |
| Indonesia 2018 | 97.3% | 89.3% | 96.2% |
| **Median** | **97.3%** | **89.3%** | **96.6%** |

Note that accuracy assessment was not performed for Malaysia and Sri Lanka, as these areas were not part of the original grant objectives. They were added on a time-as-available basis. However, the

methods used for these two countries were identical to the others analyzed, and it is assumed that similar accuracy characteristics exist.

## Supplementary Data

The following files provide detailed statistics at the subnational level for all countries mapped:

wp6_Change_Analysis_Bangladesh_1999_2014_2018.xlsx
wp6_Change_Analysis_Cambodia_1999_2014_2018.xlsx
wp6_Change_Analysis_Ecuador_1999_2014_2018.xlsx
wp6_Change_Analysis_India_1999_2014_2018.xlsx
wp6_Change_Analysis_Indonesia_1999_2014_2018.xlsx
wp6_Change_Analysis_Malaysia_1999_2014_2018.xlsx
wp6_Change_Analysis_Myanmar_1999_2014_2018.xlsx
wp6_Change_Analysis_Sri_Lanka_1999_2014_2018.xlsx
wp6_Change_Analysis_Thailand_1999_2014_2018.xlsx
wp6_Change_Analysis_Vietnam_1999_2014_2018.xlsx

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