



# Status of Fish Assemblages in Four Major Reservoirs of Thailand

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## Abstract

Fish assemblage status is essential information for practical fishery resource management in productive water bodies. This study aimed to assess fish assemblages' status and provide recommendations for practical fishery management in four major reservoirs in Thailand. Night-time samples were collected between January 2015 and December 2019 using gill net with multiple mesh sizes. Results obtained through univariate and multivariate analyses showed that the Pa Sak Jolasid Reservoir had the highest number of fish species (70), while the Rajjaprabha Reservoir had the lowest number (41). Eight species were identified as in danger of extinction and six species as alien. The percentage of the index of relative importance (% IRI) showed that the major species mainly belong to the family Cyprinidae. The forage and carnivorous fish ratio (F/C ratio) showed balanced communities in all reservoirs (4.4–9.2) except the Sirikit Reservoir (1.0). The evenness index ( $J'$ ) (0.53–0.67) and diversity index ( $H'$ ) (1.86–2.38) indicated moderate diversity and distribution in all reservoirs. Catch per unit effort (CPUE) value displayed a medium abundance in the Sirikit and Ubolratana Reservoirs (614.8 and 826.0 g.100 m<sup>-2</sup> of gill net/night, respectively), and a high abundance in the Rajjaprabha and Pa Sak Jolasid Reservoirs (1,087.2 and 1,012.5 g.100 m<sup>-2</sup> of gill net/night, respectively). In the overall assessment of fish assemblage status among the reservoirs, the Pa Sak Jolasid and Rajjaprabha Reservoirs showed the most desirable condition, while the Sirikit Reservoir showed the least desirable condition. These findings suggest the need to implement various practical fishery resource management, such as banning the introduction of invasive exotic species, and establishing conservation measures for species on the list of extinction.

**Keywords:** species and abundance, diversity indices, major reservoir, fishery management

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## Introduction

In the past, the Thai Government built large reservoirs for generating electricity or irrigation purpose and flood relief. Regardless of its purpose, the construction facilitates fish production as a source of income for local households and fish consumption as a protein source resulting in a better quality of life. Typically, the fish production in the reservoirs peak after 2–3 years. However, the status of fish abundance in the reservoirs will eventually be affected by various factors such as environmental water quality and nutrients (Phothituk and Sinchaiphanit, 1995).

As a result of reservoir construction, the essential changes in fish habitats from floodplain and river

ecosystems to reservoir environments become significant freshwater fish production sources in their own right as cheap protein food (Ingthamjitr and Sricharoendham, 2016). There are 25 large reservoirs in Thailand with a surface area of approximately 3,377.76 km<sup>2</sup> (Department of Fisheries, 2020a), and the production in 2018 was 27,706.79 tonnes with a value of about US\$50,492 (Department of Fisheries, 2020b). Nevertheless, various reservoirs have been facing several problems, including deterioration of water quality and destructive fishing practices leading to poor aquatic habitat quality and unsustainable fishery resources. Consequently, the reservoir productivity decreased, and some fish species disappeared (Ingthamjitr and Sricharoendham, 2016). The fish production in the reservoirs of Thailand has

continuously decreased from 62,961.39 tonnes in 2013 (Department of Fisheries, 2015), to 48,413.91 tonnes in 2015 (Department of Fisheries, 2017) and further reduced to 27,706.79 tonnes in 2018 (Department of Fisheries, 2020b). Therefore, assessing the status of fish assemblages in Thailand's major reservoirs is essential as a strategy to make recommendations for fishery resource management in the reservoirs, to maintain abundance and diversity of fish and its productions, and to sustain fishery resource utilisation.

This study aimed to assess the status of fish assemblages in four major reservoirs of Thailand. The study focused on species composition and abundance. Indicators set include: percentage of the index of relative importance (% IRI), forage and carnivorous fish ratio (F/C ratio), diversity indices, i.e., Margalef's species richness index ( $d$ ); Pielou's evenness index ( $J'$ ); and Shannon-Wiener species diversity index ( $H'$ ) and catch per unit effort (CPUE). Recommendations for proper fishery management implementations in the reservoirs stem from the findings.

## Materials and Methods

The study sites consisted of four major reservoirs representing water sources important in fishery from four different regions of Thailand: Sirikit Reservoir (285 km<sup>2</sup>) in Uttaradit Province (North); Ubolratana Reservoir (410 km<sup>2</sup>) in Khon Kaen Province (Northeast); Pa Sak Jolasid Reservoir (183 km<sup>2</sup>) in Lop Buri Province (Central); and, Rajjaprabha Reservoir (170 km<sup>2</sup>) in Surat Thani Province (South) (Fig. 1). The Sirikit and Rajjaprabha Reservoirs are surrounded by high mountains and forests with an average water depth of 36.6 and 30.7 m, respectively. However, the Pa Sak Jolasid and Ubolratana Reservoirs are surrounded by agricultural areas and communities with respective average water depth of 5.7 and 5.6 m (Department of Fisheries, 2020a). Fish sample collection consisted of using a set of 100 m<sup>2</sup> of gill net with multiple mesh sizes (20.0, 30.0, 40.0, 55.0, 70.0, and 90.0 mm). The mesh sizes were randomly placed overnight from sunset to sunrise (12 h a night) (Tilquin and Lechela, 1995) at four different sites of the reservoir except for five sites in the Ubolratana Reservoir. There were three replicates in each sampling occasion in each reservoir, and to account for seasonal changes in fish abundance (Potts and Reay, 1987), sampling was performed during four time intervals covering dry, wet and intermediate seasons between January 2015 and December 2019. Samples were identified to species level, according to Smith (1945), Taki (1974), and Rainboth (1996), with the individuals of each species counted and weighed. Furthermore, the identified species were checked first for the conservation status according to the IUCN red list (2020), and second, classified if alien based on Termvidchakorn et al. (2003).

Species richness and abundance were determined, and the following diversity indices were analysed to assess the diversity levels of fish among four studied reservoirs:

$$d = (S - 1) / \log_e N$$

$d$  = Margalef's species richness index

$S$  = the number of species present for a given number of individuals

$N$  = the total of individuals

$$J' = H' / \log_e S$$

$J'$  = Pielou's evenness index

$\log_e S$  = the maximum possible diversity which would be achieved if all species were equally abundant ( $=H_{max}$ )

$$H' = - \sum P_i \log_e (P_i)$$

$H'$  = Shannon-Wiener species diversity index

$P_i$  = the proportion of the total count arising from the  $i^{\text{th}}$  species

The % IRI was calculated to determine the most important species among fish species in the catches based on Caddy and Sharp (1986) as below:

$$\% \text{ IRI} = (\% N + \% W) * \% F$$

% IRI = percentage of the index of relative importance

% N = percentage of number

% W = percentage of weight

% F = percentage of frequency of occurrence

F/C ratio value was evaluated to identify the balanced or unbalanced fish communities in the reservoirs based on Swingle (1950). CPUE value was assessed for levels of abundance based on Swingle (1950). One-way analysis of variance (ANOVA) was performed to determine significant differences in CPUE value among the studied reservoirs. Also, multiple comparisons using LSD test were performed to identify significantly different means among the studied reservoirs.

Multivariate statistical analysis, i.e., hierarchical clustering, was used to classify fish community similarity (Bray-Curtis similarity). An analysis of similarity (ANOSIM) was performed to determine significant differences among groups of similarity. Similarity percentage (SIMPER) was used to test species affecting a group. Also, the ranked species abundance curve was plotted to determine the distribution patterns of the aquatic assemblages. All analysis procedures were done with PRIMER version 6.0 (Primer-E Ltd, Plymouth, U.K.) based on Clarke and Gorley (2006). Moreover, radar charting was applied to assess the overall status of the fish

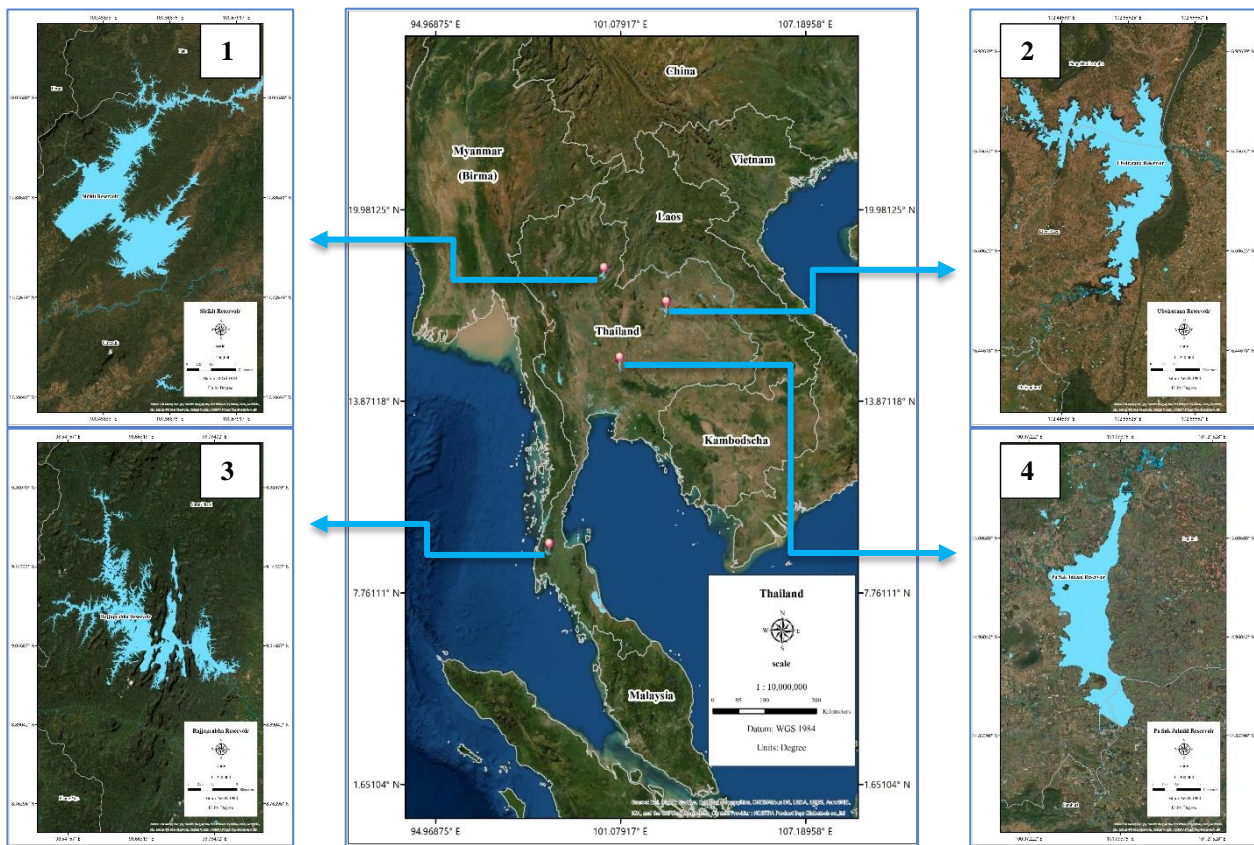


Fig. 1. Study sites of the assessment on the status of the fish assemblages in four major reservoirs of Thailand consisting of the Sirikit Reservoir, Uttaradit Province (1); the Ubolratana Reservoir, Khon Kaen Province (2); the Rajjaprabha Reservoir, Surat Thani Province (3); and the Pa Sak Jolasid Reservoir, Lop Buri Province (4).

assemblages. The values used to compare among the reservoirs were  $d$ ,  $J$ ,  $H'$ , F/C ratio, and CPUE, represented by ascending order numbers 1-4 from lower to higher. The values used to compare to standard value were  $J$ ,  $H'$ , F/C ratio, and CPUE, represented by ascending order numbers 1-3 as low to high.

## Results

### Fish species and abundance

A total of 116 fish species belong to 24 families were recorded during the surveys in four reservoirs. The highest number of species (70) was found in the Pa Sak Jolasid Reservoir, followed by the Ubolratana (65), Sirikit (45), and Rajjaprabha Reservoirs (41) (Supplementary Table 1). The average abundance was 5,768.9 individuals.year<sup>-1</sup> reservoir<sup>-1</sup>. The highest number was 8,513.8 individuals.year<sup>-1</sup> from the Pa Sak Jolasid Reservoir, followed by 5,614.3, 4,959.4 and 3,988.2 individuals.year<sup>-1</sup> from the Sirikit, Rajjaprabha and Ubolratana Reservoirs, respectively. The average biomass was 141.7 kg.year<sup>-1</sup> reservoir<sup>-1</sup>. The highest biomass was 210.1 kg.year<sup>-1</sup> from the Rajjaprabha Reservoir, followed by 186.3, 109.2 and 61.2 kg.year<sup>-1</sup> from the Pa Sak Jolasid, Sirikit and Ubolratana Reservoirs, respectively (Supplementary Table 1).

Supplementary Table 1 shows two species at risk of critically endangered (CR), i.e., *Catlocarpio siamensis* Boulenger, 1898 and *Pangasianodon gigas* Chevey, 1930; one species at the risk of endangered (EN), i.e., *Pangasianodon hypophthalmus* (Sauvage, 1878); two species at the risk of vulnerable (VU), i.e., *Cirrhinus cirrhosus* (Bloch, 1795) and *Cirrhinus microlepis* Sauvage, 1878; and three species at the risk of near threatened (NT), i.e., *Cirrhinus molitorella* (Valenciennes, 1844), *Ompok bimaculatus* (Bloch, 1794) and *Chitala blanci* (D'Aubenton, 1965). Additionally, six alien fish species were found, which included *Hypostomus plecostomus* (Linnaeus, 1758), *Oreochromis niloticus* (Linnaeus, 1758), *C. cirrhosus*, *Labeo rohita* (Hamilton, 1822), *Clarias macrocephalus* Günther, 1864 × *Clarias gariepinus* (Burchell, 1822) and *Heterotilapia buttikoferi* (Hubrecht, 1881).

### Percentage index of relative importance (% IRI)

The percentage index of relative importance for species was also assessed across the four reservoirs. As displayed in Figure 2, all reservoirs host multiple species recording values in excess of 80 %: Pa Sak Jolasid (8), Rajjaprabha (6), Sirikit (7), and Ubolratana (7).

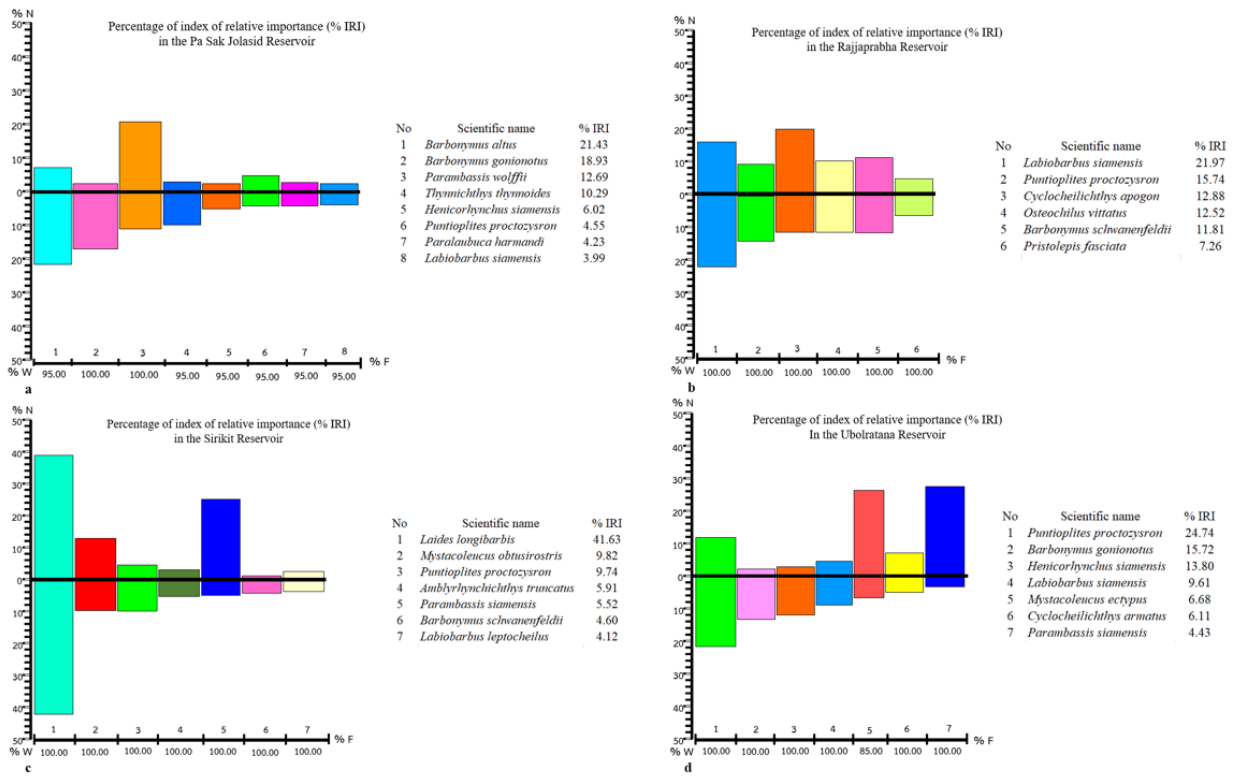


Fig. 2. Value of percentage of index of relative importance (% IRI) indicated important fish species in the four major reservoirs of Thailand; the Pa Sak Jolasid Reservoir (a), the Rajjaprabha Reservoir (b), the Sirikit Reservoir (c), and the Ubolratana Reservoir (d) with values in excess of 80 % the species for each.

### Ratio between forage and carnivorous fish (F/C ratio)

Table 1 presents the result of F/C ratio in the studied reservoirs. The Ubolratana Reservoir had the highest values (9.2), followed by the Rajjaprabha Reservoir (8.6), the Pa Sak Jolasid Reservoir (4.4), and the Sirikit Reservoir (1.0). The ratio implied that there was a balanced community in all reservoirs except the Sirikit Reservoir.

### Diversity indices

Table 2 presents the diversity indices in the four studied reservoirs. The average values of  $d$ ,  $J'$  and  $H'$  were 2.96–4.82, 0.53–0.67 and 1.86–2.38, respectively. The higher value of  $d$  was in the Pa Sak Jolasid Reservoir, and the lower value was in the Rajjaprabha Reservoir. The higher value of  $J'$  was in the Rajjaprabha Reservoir, and the lower value was in the

Sirikit Reservoir. The higher value of  $H'$  was in the Pa Sak Jolasid Reservoir, and the lower value was in the Sirikit Reservoir.

### Catch per unit effort (CPUE)

In the present study, CPUE value varied among reservoirs with values of 614.8–1,087.2 g.100 m<sup>-2</sup> of gill net/night. The highest value was in the Rajjaprabha Reservoir, and the lowest was in the Sirikit Reservoir. Also, the result of ANOVA showed the significant difference in CPUE value among the reservoirs ( $P < 0.05$ ) where the values of the Pa Sak Jolasid and Rajjaprabha Reservoirs were higher than the Sirikit and Ubolratana Reservoirs ( $P < 0.05$  of LSD test). When considering CPUE according to the gill net mesh sizes, the study found the highest CPUE in 20.0 mm mesh gill nets operated in the Ubolratana Reservoir. Other reservoirs achieved higher CPUE in gill nets of mesh sizes of 30.0 and 40.0 mm (Table 3).

Table 1. Ratio of forage and carnivorous fish (F/C ratio) opened value in the four major reservoirs of Thailand. The value was calculated from the production of forage fish (F) divided by the production of carnivorous fish (C).

| Types of fish        | Pa Sak Jolasid | Rajjaprabha | Sirikit | Ubolratana | Total     |
|----------------------|----------------|-------------|---------|------------|-----------|
| Forage fish (g)      | 725,942        | 908,869     | 163,401 | 258,415    | 2,056,627 |
| Carnivorous fish (g) | 164,292        | 105,179     | 157,641 | 28,177     | 455,289   |
| Value of F/C ratio   | 4.4            | 8.6         | 1.0     | 9.2        | 4.5       |

Table 2. Diversity indices show the values in the four major reservoirs of Thailand. The values comprise with species richness index ( $d$ ), evenness index ( $J'$ ), and diversity index ( $H'$ ).

| Year    | Diversity indices | Reservoirs     |             |         |            |
|---------|-------------------|----------------|-------------|---------|------------|
|         |                   | Pa Sak Jolasid | Rajjaprabha | Sirikit | Ubolratana |
| 2015    | $d$               | 4.92           | 2.62        | ND      | 4.85       |
|         | $J'$              | 0.63           | 0.69        | ND      | 0.50       |
|         | $H'$              | 2.41           | 2.15        | ND      | 1.88       |
| 2016    | $d$               | 4.47           | 2.85        | ND      | 5.47       |
|         | $J'$              | 0.65           | 0.69        | ND      | 0.66       |
|         | $H'$              | 2.35           | 2.22        | ND      | 2.52       |
| 2017    | $d$               | 5.15           | 2.87        | 3.71    | 5.16       |
|         | $J'$              | 0.64           | 0.70        | 0.54    | 0.60       |
|         | $H'$              | 2.48           | 2.25        | 1.89    | 2.26       |
| 2018    | $d$               | 4.49           | 3.23        | 3.59    | 3.91       |
|         | $J'$              | 0.58           | 0.64        | 0.52    | 0.53       |
|         | $H'$              | 2.16           | 2.16        | 1.81    | 1.86       |
| 2019    | $d$               | 5.07           | 3.24        | 3.94    | 4.08       |
|         | $J'$              | 0.65           | 0.61        | 0.53    | 0.56       |
|         | $H'$              | 2.52           | 2.06        | 1.87    | 2.01       |
| Average | $d$               | 4.82           | 2.96        | 3.75    | 4.70       |
|         | $J'$              | 0.63           | 0.67        | 0.53    | 0.57       |
|         | $H'$              | 2.38           | 2.17        | 1.86    | 2.10       |

Table 3. Catch per unit effort (CPUE)(g.100 m<sup>2</sup> of gill net/night) exposed value in Thailand's four major reservoirs. The value was estimated by multiple mesh sizes of gill net of each reservoir.

| Mesh sizes of gill net (mm) | Value of CPUE (g.100 m <sup>2</sup> of gill net/night) |                      |                    |                    |
|-----------------------------|--|----------------------|--------------------|--------------------|
|                             | Pa Sak Jolasid   | Rajjaprabha          | Sirikit            | Ubolratana         |
| 20.0                        | 642.8  | 317.4                | 1,086.6            | 2,274.4            |
| 30.0                        | 1,235.5  | 1,223.0              | 1,378.6            | 812.0              |
| 40.0                        | 1,422.7  | 2,748.1              | 623.3              | 613.3              |
| 55.0                        | 1,321.1  | 1,190.8              | 383.0              | 644.4              |
| 70.0                        | 856.2  | 689.3                | 146.8              | 351.4              |
| 90.0                        | 596.9  | 354.6                | 70.7               | 260.7              |
| Average                     | 1,012.5 <sup>a</sup>                                   | 1,087.2 <sup>a</sup> | 614.8 <sup>b</sup> | 826.0 <sup>b</sup> |

Superscript alphabets represent different CPUE values among reservoirs.

### Species abundant distribution

The results of the ranked species abundant curves display two patterns (Fig. 3). First, a high cumulative percentage of the dominant species in the Sirikit Reservoir, i.e., *Laides longibarbis* (Fowler, 1934). Second, a low cumulative percentage of the first species in the Ubolratana, Rajjaprabha and Pa Sak Jolasid Reservoirs. These are now dominant species in the communities.

### Hierarchical clustering of fish abundance

The clustering analysis grouped abundant fish

similarity into three groups cutting off at 50.20 % of similarity with ANOSIM test of  $R = 1.0$  and  $P = 0.17$ ; group 1 consisting the Pa Sak Jolasid and Ubolratana Reservoirs, group 2 containing the Rajjaprabha Reservoir, and group 3 covering the Sirikit Reservoir (Fig. 4). At species contributing to 10 % or higher, *Parambassis siamensis* (Fowler, 1937), *Puntioplites proctozysron* (Bleeker, 1865) and *Cyclocheilichthys armatus* (Valenciennes, 1842) indicated similarity within group 1. However, the similarity of species contribution between group 1 and 2 is incomplete because there are less than two samples in a group.

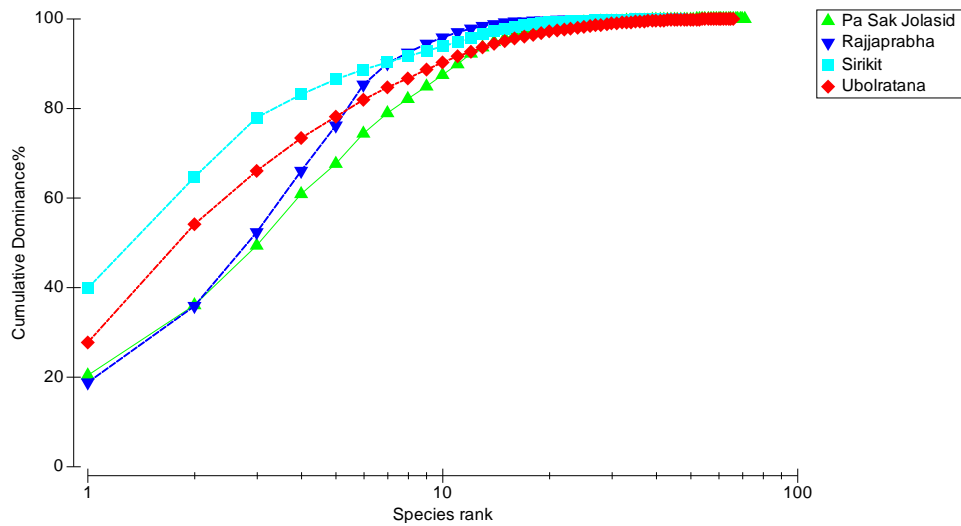


Fig. 3. Curvatures display species abundant distribution of fish assemblages in the reservoirs of Thailand. The curve of the Sirikit Reservoir shows higher cumulative percentage of the first species, which was dominated by certain species. In comparison, the other curves show lower cumulative percentage of the first species.

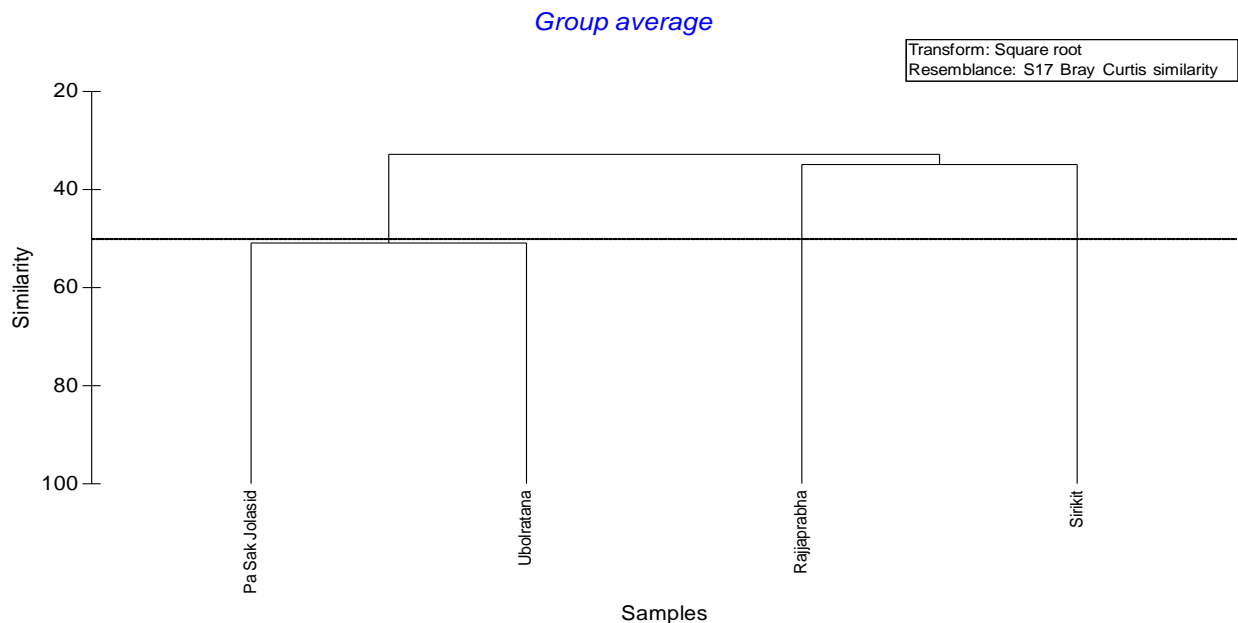


Fig. 4. Clustering provided abundant fish similarity in the four major reservoirs of Thailand into three groups cut at 50.20 % of similarity with ANOSIM test of  $R = 1.0$  and  $P = 0.17$ . The Pa Sak Jolasid and Ubolratana Reservoirs were classified as group 1, the Rajjaprabha Reservoir as group 2, and the Sirikit Reservoir as group 3.

### Overall fish assemblage status

The overall status of fish assemblages among the studied reservoirs with values of  $d$ ,  $J'$ ,  $H'$ , F/C ratio and CPUE is shown in Figure 5a. The Pa Sak Jolasid Reservoir had the best status, followed by the Ubolratana, Rajjaprabha, and Sirikit Reservoirs. Comparing values of  $J'$ ,  $H'$ , F/C ratio, and CPUE with standard values, revealed that the satisfactory status of fish assemblages was in the Pa Sak Jolasid and Rajjaprabha Reservoirs, followed by the Ubolratana Reservoir, while registering and the poorest status in the Sirikit Reservoirs due to its lower F/C ratio value (Fig. 5b).

### Discussion

According to the results, the fish species richness found in each reservoir did not differ much compared to previous studies, i.e., 70, 41, 45 and 65 species in the Pa Sak Jolasid, Rajjaprabha, Sirikit and Ubolratana Reservoirs, respectively. There is no apparent relationship between the reservoir extent and species richness as reported by Amarasinghe and Welcomme (2002) possibly due to regular stocking of fish species in Thai reservoirs. However, some variations in species diversity may have resulted from different sampling methods and the study period. The previous study reported 53 and 38 species in the Ubolratana

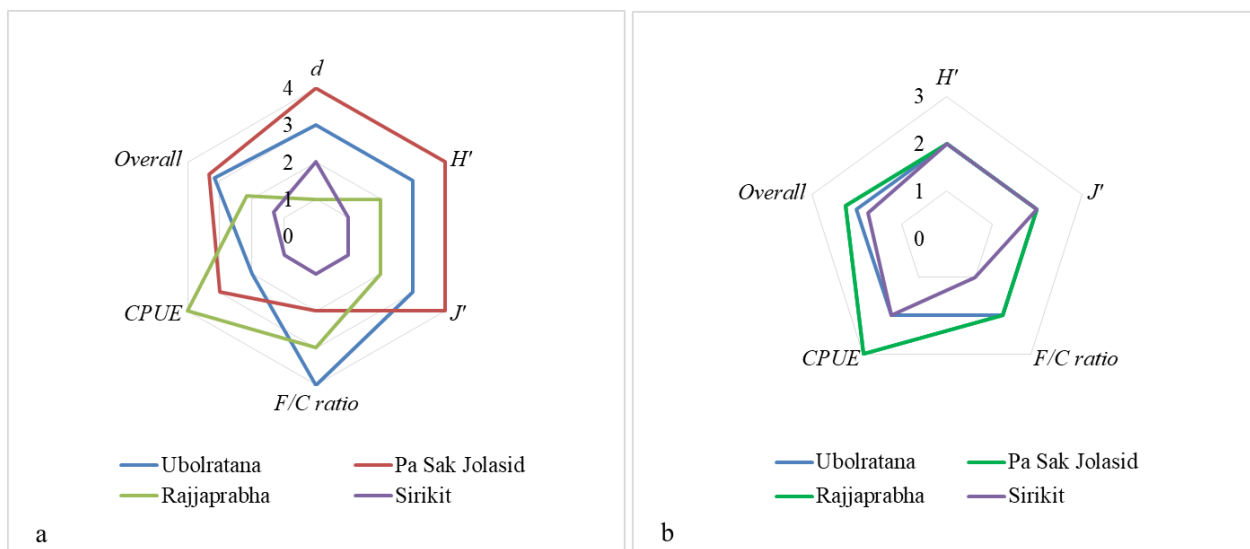


Fig. 5. Radar graphs showing overall status of fish assemblages in the four major reservoirs of Thailand. (a) Comparison of species richness index ( $d$ ), evenness index ( $J'$ ), diversity index ( $H'$ ), forage and carnivorous fish ratio (F/C ratio), and catch per unit effort (CPUE) among each reservoir. (b) Comparison of evenness index ( $J'$ ), diversity index ( $H'$ ), forage and carnivorous fish ratio (F/C ratio), and catch per unit effort (CPUE) in each reservoir with standard values.

and Rajjaprabha Reservoirs, respectively (Dumrongtripob et al., 2009), 44 species in the Sirikit Reservoir (Soe-been and Panboon, 2011), and 48 species in the Pa Sak Jolasid Reservoir (Thanasomwang, 2013). The Ubolratana Reservoir showed the lowest both individuals and biomass in terms of abundance, which implies that this reservoir has a smaller sized fish than other studied reservoirs. In contrast, the Rajjaprabha Reservoir had slightly smaller-sized individuals but with the highest biomass. Also, eight species were found in danger of extinction. Fishery management should facilitate breeding techniques and stock enhancement through fish stocking to increase productivity and maintain biodiversity. Habitat conservation and fishing control should also be strongly considered. In addition, some alien fish species were found. Non-invasive alien fish species have been intentionally restocked to increase fish production (i. e., *O. niloticus*, *C. cirrhosus*, and *L. rohita*). However, invasive alien fish species (i.e., *H. plecostomus*, *C. macrocephalus* × *C. gariepinus*, and *H. buttikoferi*) perhaps were accidentally released into the waters. The invasive alien species have a serious impact on local biota, causing decline or even extinction of native species, and negatively affecting the ecosystems (Convention on Biological Diversity, 2020). Hence, the spread of invasive exotic species should be controlled.

The percent IRI with values of above 80 % were mainly species from the family Cyprinidae which was the same as the study of Dumrongtripob et al. (2009) in the Pa Sak Jolasid, Rajjaprabha and Ubolratana Reservoirs. Remarkably, *L. longibarbis* which is carnivorous fish in the Sirikit Reservoir, showed high percentages (41.63 %), unlike in a previous study (Soe-been and Panboon, 2011) which reported that cyprinids were the main species. The high proportions

of cyprinid species distort the balance of the fish assemblages. The low F/C ratio (value 1.0) displayed the unbalanced assemblages in the Sirikit Reservoir, while the other reservoirs displayed balanced assemblages (value 4.4 - 9.2). The disproportionate assemblage in Sirikit Reservoir was due to higher carnivorous fish than forage fish. In a balanced assemblage, the F/C ratio ranged from 1.4 to 10 (Swingle, 1950). The unbalanced fish assemblages cannot sustain productive fisheries (Swingle, 1950). Moreover, when the carnivorous fish is dominant in the water body, the F/C ratio is unbalanced, and as a result, the fish biomass is lower (Sultana, 2012). Also, the carnivorous species should be strictly managed to balance the fish assemblages in the Sirikit Reservoir. However, previous studies of F/C ratio showed balanced assemblages in the Rajjaprabha (2.1) (Dumrongtripob et al., 2009), Ubolratana (2.9) (Nachaiapherm and Musikaew, 2006), and Sirikit Reservoirs (1.4) (Panboon and Soe-been, 2011).

When considering the diversity indices in the water bodies, Harper and Hawksworth (1994), and Purvis and Hector (2000) state that there is no single measure or single dimension, e.g., species richness or abundance for assessment of diversity levels. Also, Begon et al. (1990) stated that the  $J'$  value ranges between 0.0 and 1.0, with 1.0 representing a situation in which all species are equally abundant. The  $H'$  value is generally between 1.5 and 3.5, where a high value indicates healthy species diversity, and the  $H'$  value can be applied to assess the environmental conditions. Wilhm and Dorris (1968) proposed a relationship between the  $H'$  value and pollution status of water that the  $H'$  value of >3 is an indication of clean water. The value 1-3 is moderately polluted water and the value <1 is heavily contaminated water. Moreover, Tudorancea et al. (1979) advised that the  $H'$  value of 1-3

is moderate for aquatic organisms, and the value of  $>3$  is highly suitable. Thus, the diversity and distribution status of the fish assemblages in the four reservoirs was moderate. The water was moderately-polluted, though still acceptable for aquatic organism growth and survival. In addition, the diversity indices in this study did not differ much from previous studies excluding  $d$  value of the Sirikit reservoir. The values of  $d$ ,  $J'$  and  $H'$  reported by Dumrongtripob et al. (2009) in the Rajjaprabha Reservoir were 3.10, 0.60 and 3.10, and in the Ubolratana Reservoir were 5.10, 0.60 and 3.00, respectively. Whereas such values in the Pa Sak Jolasid Reservoir as reported by Thanasomwang (2013) were 12.42, 0.57 and 2.22, and in the Sirikit reservoir as reported by Panboon et al. (2015) were 3.02, 0.62 and 1.98, respectively.

The CPUE is an indicator of the relative abundance of fish and other nekton in waters. It described as the number and weight of fish caught during 12 h of fishing. Measuring catches either by number or weight may give very different results (Naesje et al., 2004; Ajith Kumara et al., 2009). However, in this study's results were presented by weight only because it provides a better indication of the amount of fish protein, and is more important to fishers and fishery managers (Naesje et al., 2004; Preecha et al., 2011). Also, for relative abundance of fish, the criteria of CPUE at four levels for 100 m<sup>2</sup> of gill net/night was determined as follows; 1) less than 500: low abundance, 2) 500–1,000: moderate abundance, 3) 1,000–2,000: high abundance, and 4) more than 2,000: very high abundance (Sricharoendham et al., 2015). Thus, the CPUE values as shown in Table 3 indicated high fish abundance in the Pa Sak Jolasid and Rajjaprabha Reservoirs, while the Sirikit and Ubolratana Reservoirs showed a moderate abundance of fish. Of note, the present values of CPUE varied positively from those previously reported by Dumrongtripob et al. (2009): for the Rajjaprabha Reservoir (762.0 g.100 m<sup>2</sup> of gill net/night), the Pa Sak Jolasid Reservoir (836.0 g.100 m<sup>2</sup> of gill net/night), and the Ubolratana Reservoir (350.0 g.100 m<sup>2</sup> of gill net/night), as well as reported by Soe-been and Panboon (2011) for the Sirikit Reservoir as 555.58 g.100 m<sup>2</sup> of gill net/night. Although the Sirikit Reservoir indicated moderate abundance, it showed the lowest CPUE value among four reservoirs. Therefore, it is suggested that effective fishery management needs to implement strict measures to increase fish production in this reservoir. When the gill net's mesh sizes were taken into consideration, the most abundant species distribution was associated with a maximum weight in the gill nets of 20.0 mm mesh in the Ubolratana Reservoir, indicating that the small fishes are as the main structure in this reservoir. In contrast a maximum weight of fish in gill nets of 30.0 and 40.0 mm mesh sizes were found in the Pa Sak Jolasid, Rajjaprabha Reservoir and Sirikit Reservoirs, implying that the medium fishes are the core component in these reservoirs.

The abundance curve resulted in some dominant species at a high cumulative percentage in the Sirikit Reservoirs i. e. *L. longibarbis* (carnivorous fish). This evidence further indicates that fishery management should consider maintaining balanced assemblage in this reservoir. The cluster analysis grouped the Pa Sak Jolasid and Ubolratana Reservoirs contributing by *P. siamensis*, *P. proctozysron* and *C. armatus*, similar to abundance.

Finally, overall fish assemblage status was more desirable in the Pa Sak Jolasid and Rajjaprabha Reservoirs, but less desirable status was recorded in the Sirikit Reservoir. Therefore, the Sirikit Reservoir's fishery needs better attention in fishery management.

The following recommendations support practical fishery resource management for the studied reservoirs. In essence, fishery resource management agencies should:

i) Preserve aquatic biodiversity, especially species at risk of extinction in nature, by applying breeding techniques and stocking programs. Moreover, consideration should be given for fish habitat conservation and fishing control.

ii) Promote utilisation of small-sized fish species that form the main component in the reservoirs, especially in the Ubolratana Reservoir, by adding value in food processing and being used as an animal feed ingredient.

iii) Eradicate or control the invasive exotic species population, which have negative impacts on aquatic ecosystems. This could manifest in several ways: first, the authority agencies could introduce a "bounty" (financial compensation) for every dead invasive alien fish, or preferably, create a regulated market for them; and second, promote people or entrepreneurs to utilise them for animal or human consumption, as well as organic fertiliser. Such measures would encourage people to catch them excessively. Thirdly, and the complementary, measure would be to publicise that unauthorised propagation, holding and releasing of such species is banned by law strictly with subsequent penalties for breaches.

iv) Rebuild the balance between herbivorous fish and carnivorous fish, especially in the Sirikit Reservoir, by promoting predatory fish harvesting and restocking herbivorous fish programs to achieve a balanced assemblage.

v) Prioritise fishery management development in the Sirikit Reservoir to increase productivity and reduce carnivorous fishes' abundance.

## Conclusion

Species richness of the four major reservoirs in Thailand varied positively from those reported in



previous studies. The Pa Sak Jolasid showed the most significant improvement while the Rajjaprabha showed the least, though still a healthy change. Eight endangered species were identified; two for critically endangered, one for endangered, two for vulnerable, and three for near-threatening, which require better conservation measures. Six alien fish species were classified, including three non-invasive, and three invasive species, thus requiring additional fisheries management interventions. The percent IRI showed the important species, mainly under family Cyprinidae, and other small size fishes. The forage and carnivorous fish ratio among studied reservoirs mostly implied balanced communities. The notable exception was seen in the Sirikit Reservoir, showing low value of this ratio (1.0) that require further studies to rebuild a balanced community. The  $J'$  and  $H'$  indicated the status of fish in medium diversity and distribution across all reservoirs, showing still satisfactory ecosystem or environment conditions.

While the catch per unit effort presented a high abundance in the Pa Sak Jolasid and Rajjaprabha Reservoirs, only moderate abundance showed in the Sirikit and Ubolratana Reservoirs. Although the later are still considered acceptable, further research is required to understand the variations for further improvement. According to species abundance there are no dominant species in the assemblages in the studied reservoirs, with exception to the Sirikit Reservoir, where *L. longibarbis* was found to be dominant.

In conclusion, overall fish assemblage status across the reservoirs exposed the Pa Sak Jolasid and Rajjaprabha Reservoirs as the most desirable condition and the Sirikit Reservoir as the least desirable condition. Immediate implementation for various practical fishery resource management, such as reducing invasive exotic species population size, and establishing conservation measures for species on the extinction list is recommended.

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Supplementary Table 1. Species and abundance of fish found in the four major reservoirs of Thailand.

| Family/Scientific name   | Reservoirs     |             |         |            | Status        |             |
|--|----------------|-------------|---------|------------|---------------|-------------|
|  | Pa Sak Jolasid | Rajjaprabha | Sirikit | Ubolratana | IUCN red list | Local/Alien |
| <b>1. Notopteridae</b>   |                |             |         |            |               |             |
| 1. <i>Notopterus notopterus</i> (Pallas, 1769)                 | +              | ++          | +       | +          | LC            | Local       |
| 2. <i>Chitala ornata</i> (Gray, 1831)                          | +              | -           | -       | +          | LC            | Local       |
| 3. <i>Chitala blanci</i> (D'Aubenton, 1965)                    | -              | +           | -       | -          | NT            | Local       |
| 4. <i>Chitala lopis</i> (Bleeker, 1851)                        | -              | +           | -       | -          | LC            | Local       |
| <b>2. Clupeidae</b>  |                |             |         |            |               |             |
| 5. <i>Clupeichthys aesarnensis</i> Wongratana, 1983            | +++            | -           | -       | ++         | LC            | Local       |
| 6. <i>Clupeichthys goniognathus</i> Bleeker, 1855              | -              | -           | ++      | -          | LC            | Local       |
| <b>3. Cyprinidae</b>   |                |             |         |            |               |             |
| 7. <i>Paralaubuca harmandi</i> Sauvage, 1883                   | +++            | -           | -       | ++         | LC            | Local       |
| 8. <i>Parachela siamensis</i> (Günther, 1868)                  | +              | -           | -       | ++         | LC            | Local       |
| 9. <i>Parachela willaminae</i> Fowler, 1934                    | -              | -           | -       | +          | LC            | Local       |
| 10. <i>Parachela maculicauda</i> (Smith, 1934)                 | ++             | -           | -       | -          | LC            | Local       |
| 11. <i>Luciosoma bleekeri</i> Steindachner, 1878               | -              | -           | -       | +          | LC            | Local       |
| 12. <i>Leptobarbus hoevenii</i> (Bleeker, 1851)                | -              | +           | -       | -          | NE            | Local       |
| 13. <i>Rasbora aurotaenia</i> Tirant, 1885                     | ++             | -           | -       | -          | LC            | Local       |
| 14. <i>Rasbora dusonensis</i> (Bleeker, 1850)                  | -              | -           | -       | +          | NE            | Local       |
| 15. <i>Rasbora tornieri</i> Ahl, 1922                          | -              | +           | -       | +          | LC            | Local       |
| 16. <i>Neolissochilus stracheyi</i> (Day, 1871)                | -              | +           | -       | -          | LC            | Local       |
| 17. <i>Amblyrhynchichthys truncatus</i> (Bleeker, 1850)        | -              | -           | ++      | -          | LC            | Local       |
| 18. <i>Amblyrhynchichthys micracanthus</i> Ng & Kottelat, 2004 | -              | +           | -       | -          | LC            | Local       |
| 19. <i>Cosmochilus harmandi</i> Sauvage, 1878                  | +              | -           | -       | -          | LC            | Local       |
| 20. <i>Cyclocheilichthys apogon</i> (Valenciennes, 1842)       | ++             | +++         | ++      | ++         | LC            | Local       |
| 21. <i>Cyclocheilichthys armatus</i> (Valenciennes, 1842)      | +++            | ++          | ++      | +++        | LC            | Local       |
| 22. <i>Cyclocheilichthys enoplos</i> (Bleeker, 1849)           | ++             | -           | ++      | -          | LC            | Local       |
| 23. <i>Cyclocheilichthys heteronema</i> (Bleeker, 1854)        | -              | ++          | -       | -          | LC            | Local       |
| 24. <i>Mystacoleucus marginatus</i> (Valenciennes, 1842)       | +              | +++         | +++     | -          | LC            | Local       |
| 25. <i>Mystacoleucus ectypus</i> Kottelat, 2000                | -              | -           | -       | +++        | LC            | Local       |
| 26. <i>Puntius proctozyron</i> (Bleeker, 1865)                 | +++            | +++         | ++      | +++        | LC            | Local       |
| 27. <i>Sikukia gudgeri</i> (Smith, 1934)                       | -              | -           | -       | ++         | DD            | Local       |
| 28. <i>Barbonymus altus</i> (Günther, 1868)                    | +++            | +           | ++      | +          | LC            | Local       |
| 29. <i>Barbonymus gonionotus</i> (Bleeker, 1849)               | ++             | +           | +       | ++         | LC            | Local       |
| 30. <i>Barbonymus schwanenfeldii</i> (Bleeker, 1854)           | +              | +++         | ++      | +          | LC            | Local       |
| 31. <i>Discherodontus ashmeadi</i> (Fowler, 1937)              | -              | -           | +       | -          | LC            | Local       |
| 32. <i>Hampala dispar</i> Smith, 1934                          | +              | -           | -       | +          | LC            | Local       |
| 33. <i>Hampala macrolepidota</i> Kuhl & Van Hasselt, 1823      | ++             | ++          | ++      | ++         | LC            | Local       |
| 34. <i>Puntius brevis</i> (Bleeker, 1849)                      | +              | ++          | +       | ++         | LC            | Local       |
| 35. <i>Systemus rubripinnis</i> (Valenciennes, 1842)           | -              | -           | +       | +          | DD            | Local       |
| 36. <i>Puntius partipentazona</i> (Fowler, 1934)               | -              | +           | -       | +          | LC            | Local       |
| 37. <i>Catlocarpio siamensis</i> Boulenger, 1898               | -              | -           | -       | +          | CR            | Local       |
| 38. <i>Thynnichthys thynnoides</i> (Bleeker, 1852)             | +++            | +           | -       | -          | LC            | Local       |
| 39. <i>Cirrhinus microlepis</i> Sauvage, 1878                  | +              | -           | -       | +          | VU            | Local       |
| 40. <i>Cirrhinus cirrhosus</i> (Bloch, 1795)                   | +              | -           | +       | -          | VU            | Alien       |
| 41. <i>Cirrhinus molitorella</i> (Valenciennes, 1844)          | +              | -           | -       | -          | NT            | Local       |
| 42. <i>Labiobarbus leptocheilus</i> (Valenciennes, 1842)       | -              | -           | ++      | -          | LC            | Local       |
| 43. <i>Labiobarbus siamensis</i> (Sauvage, 1881)               | +++            | +++         | -       | ++         | LC            | Local       |
| 44. <i>Henicorhynchus siamensis</i> (Sauvage, 1881)            | +++            | -           | +       | ++         | LC            | Local       |
| 45. <i>Henicorhynchus lobatus</i> Smith, 1945                  | -              | -           | -       | +          | LC            | Local       |
| 46. <i>Labeo rohita</i> (Hamilton, 1822)                       | +              | +           | -       | +          | LC            | Alien       |
| 47. <i>Labeo chrysophekadian</i> (Bleeker, 1849)               | +              | -           | +       | +          | LC            | Local       |
| 48. <i>Labocheilus melanotaenia</i> (Fowler, 1935)             | -              | -           | -       | +          | LC            | Local       |
| 49. <i>Osteochilus vittatus</i> (Valenciennes, 1842)           | +              | +++         | -       | ++         | LC            | Local       |
| 50. <i>Osteochilus lini</i> Fowler, 1935                       | +              | -           | -       | -          | LC            | Local       |

| Family/Scientific name  | Reservoirs     |             |         |            | Status        |             |
|---|----------------|-------------|---------|------------|---------------|-------------|
|   | Pa Sak Jolasid | Rajjaprabha | Sirikit | Ubolratana | IUCN red list | Local/Alien |
| 51. <i>Osteochilus scapularis</i> Fowler, 1939  | +              | -           | -       | +          | LC            | Local       |
| 52. <i>Osteochilus microcephalus</i> (Valenciennes, 1842)                                   | +              | +           | -       | +          | LC            | Local       |
| 53. <i>Osteochilus waandersii</i> (Bleeker, 1853)   | +              | +           | -       | -          | LC            | Local       |
| 54. <i>Crossocheilus cobitis</i> (Bleeker, 1854)  | -              | -           | -       | +          | NE            | Local       |
| 55. <i>Crossocheilus oblongus</i> Kuhl & Van Hasselt, 1823                                  | -              | -           | +       | -          | LC            | Local       |
| 56. <i>Crossocheilus atrilimes</i> Kottelat, 2000   | -              | -           | +       | -          | LC            | Local       |
| 57. <i>Crossocheilus reticulatus</i> (Fowler, 1934)   | -              | -           | +       | -          | LC            | Local       |
| 58. <i>Epalzeorhynchus frenatus</i> (Fowler, 1934)  | -              | -           | +       | -          | LC            | Local       |
| <b>4. Cobitidae</b>   |                |             |         |            |               |             |
| 59. <i>Syncrossus hymenophysa</i> (Bleeker, 1852)   | +              | -           | -       | +          | LC            | Local       |
| 60. <i>Yasuhikotakia modesta</i> (Bleeker, 1864)  | +              | -           | +       | +          | LC            | Local       |
| 61. <i>Yasuhikotakia morleti</i> (Tirant, 1885)   | +              | -           | -       | +          | LC            | Local       |
| 62. <i>Acantopsis dialuzona</i> Van Hasselt, 1823   | +              | -           | -       | +          | LC            | Local       |
| <b>5. Gyrinocheilidae</b>   |                |             |         |            |               |             |
| 63. <i>Gyrinocheilus aymonieri</i> (Tirant, 1883)   | -              | -           | -       | +          | LC            | Local       |
| <b>6. Bagridae</b>  |                |             |         |            |               |             |
| 64. <i>Pseudomystus siamensis</i> (Regan, 1913)   | +              | -           | -       | -          | LC            | Local       |
| 65. <i>Mystus singaringan</i> (Bleeker, 1846)   | +              | -           | +       | +          | LC            | Local       |
| 66. <i>Mystus albolineatus</i> Roberts, 1994  | -              | -           | -       | +          | LC            | Local       |
| 67. <i>Mystus multiradiatus</i> Roberts, 1992   | +              | -           | -       | +          | LC            | Local       |
| 68. <i>Mystus mysticetus</i> Roberts, 1992  | ++             | -           | -       | +          | LC            | Local       |
| 69. <i>Hemibagrus nemurus</i> (Valenciennes, 1840)  | -              | +           | +       | +          | DD            | Local       |
| 70. <i>Hemibagrus filamentus</i> (Fang & Chauv, 1949)                                       | +              | ++          | +       | -          | LC            | Local       |
| <b>7. Siluridae</b>   |                |             |         |            |               |             |
| 71. <i>Kryptopterus cheveyi</i> Durand, 1940  | ++             | -           | +       | +          | DD            | Local       |
| 72. <i>Micronema hexapterus</i> (Bleeker, 1851)   | -              | -           | +       | -          | NE            | Local       |
| 73. <i>Kryptopterus palembangensis</i> (Bleeker, 1852)                                      | +              | -           | -       | -          | NE            | Local       |
| 74. <i>Kryptopterus geminus</i> Ng, 2003  | ++             | -           | -       | -          | LC            | Local       |
| 75. <i>Phalacronotus apogon</i> (Bleeker, 1851)   | +              | -           | -       | +          | LC            | Local       |
| 76. <i>Phalacronotus bleekeri</i> (Gunther, 1864)   | +              | -           | +       | +          | LC            | Local       |
| 77. <i>Phalacronotus micronema</i> (Bleeker, 1846)  | -              | -           | +       | -          | LC            | Local       |
| 78. <i>Ompok bimaculatus</i> (Bloch, 1794)  | -              | +           | -       | +          | NT            | Local       |
| <b>8. Pangasiidae</b>   |                |             |         |            |               |             |
| 79. <i>Pangasianodon gigas</i> Chevey, 1931   | +              | -           | -       | -          | CR            | Local       |
| 80. <i>Pangasianodon hypophthalmus</i> (Sauvage, 1878)                                      | ++             | -           | +       | +          | EN            | Local       |
| 81. <i>Pangasius larnaudii</i> Bocourt, 1866  | +              | -           | -       | -          | LC            | Local       |
| 82. <i>Pangasius macronema</i> Bleeker, 1850  | -              | -           | +       | -          | LC            | Local       |
| 83. <i>Pseudolais pleurotaenia</i> (Sauvage, 1878)  | ++             | -           | -       | -          | LC            | Local       |
| 84. <i>Lrides longibarbis</i> (Fowler, 1934)  | -              | -           | +++     | -          | LC            | Local       |
| <b>9. Clariidae</b>   |                |             |         |            |               |             |
| 85. <i>Clarias gariepinus</i> (Burchell, 1822)  | -              | -           | +       | -          | LC            | Local       |
| 86. <i>Clarias macrocephalus</i> Günther, 1864 × <i>Clarias gariepinus</i> (Burchell, 1822) | +              | -           | -       | -          | LC            | Alien       |
| <b>10. Belontiidae</b>  |                |             |         |            |               |             |
| 87. <i>Xenentodon cancila</i> (Hamilton, 1822)  | +              | +           | +       | +          | LC            | Local       |
| <b>11. Hemiramphidae</b>  |                |             |         |            |               |             |
| 88. <i>Zenarchopterus ectuntia</i> (Hamilton, 1822)   | +              | -           | -       | -          | NE            | Local       |
| <b>12. Syngnathidae</b>   |                |             |         |            |               |             |
| 89. <i>Doryichthys boaja</i> (Bleeker, 1850)  | +              | -           | -       | -          | DD            | Local       |
| <b>13. Mastacembelidae</b>  |                |             |         |            |               |             |
| 90. <i>Macrogathus siamensis</i> (Günther, 1861)  | +              | +           | -       | +          | LC            | Local       |
| 91. <i>Macrogathus taeniogaster</i> (Fowler, 1935)  | -              | -           | -       | +          | NE            | Local       |
| 92. <i>Macrogathus circumcinctus</i> (Hora, 1924)   | +              | -           | -       | -          | LC            | Local       |
| 93. <i>Macrogathus semiocellatus</i> Roberts, 1986  | +              | -           | +       | +          | LC            | Local       |
| 94. <i>Mastacembelus armatus</i> (Lacepede, 1800)   | -              | +           | -       | +          | LC            | Local       |

| Family/Scientific name                                 | Reservoirs     |             |            |            | Status        |             |
|--|----------------|-------------|------------|------------|---------------|-------------|
|  | Pa Sak Jolasid | Rajjaprabha | Sirikit    | Ubolratana | IUCN red list | Local/Alien |
| 95. <i>Mastacembelus tinwhini</i> Britz, 2007          | -              | +           | -          | -          | LC            | Local       |
| 96. <i>Mastacembelus favus</i> Hora, 1924              | +              | +           | +          | +          | LC            | Local       |
| <b>14. Channidae</b>                                   |                |             |            |            |               |             |
| 97. <i>Parambassis siamensis</i> (Fowler, 1937)        | +++            | +           | +++        | +++        | LC            | Local       |
| 98. <i>Parambassis apogonoides</i> (Bleeker, 1851)     | +++            | -           | -          | -          | LC            | Local       |
| 99. <i>Parambassis wolffii</i> (Bleeker, 1850)         | +++            | -           | -          | -          | LC            | Local       |
| <b>15. Toxotidae</b>                                   |                |             |            |            |               |             |
| 100. <i>Toxotes chatareus</i> (Hamilton, 1822)         | +              | -           | +          | -          | LC            | Local       |
| <b>16. Nandidae</b>                                    |                |             |            |            |               |             |
| 101. <i>Pristolepis fasciata</i> (Bleeker, 1851)       | +              | +++         | +          | +          | LC            | Local       |
| <b>17. Cichlidae</b>                                   |                |             |            |            |               |             |
| 102. <i>Oreochromis niloticus</i> (Linnaeus, 1758)     | +              | +           | +          | +          | LC            | Alien       |
| 103. <i>Heterotilapia buttikoferi</i> (Hubrecht, 1881) | -              | -           | +          | -          | LC            | Alien       |
| <b>18. Eleotridae</b>                                  |                |             |            |            |               |             |
| 104. <i>Oxyeleotris marmorata</i> (Bleeker, 1852)      | +              | ++          | +          | ++         | LC            | Local       |
| <b>19. Osphronemidae</b>                               |                |             |            |            |               |             |
| 105. <i>Trichopodus pectoralis</i> Regan, 1910         | -              | -           | -          | +          | LC            | Local       |
| 106. <i>Trichopodus trichopterus</i> (Pallas, 1770)    | +              | -           | -          | +          | LC            | Local       |
| 107. <i>Trichopodus microlepis</i> (Günther, 1861)     | +              | -           | -          | -          | LC            | Local       |
| 108. <i>Osphronemus goramy</i> Lacepede, 1801          | -              | +           | -          | -          | LC            | Local       |
| <b>20. Channidae</b>                                   |                |             |            |            |               |             |
| 109. <i>Channa micropeltes</i> (Cuvier, 1831)          | +              | +           | -          | -          | LC            | Local       |
| 110. <i>Channa striata</i> (Bloch, 1793)               | -              | +           | +          | +          | LC            | Local       |
| <b>21. Soleidae</b>                                    |                |             |            |            |               |             |
| 111. <i>Brachirus panoides</i> (Bleeker, 1851)         | -              | -           | -          | +          | LC            | Local       |
| <b>22. Tetraodontidae</b>                              |                |             |            |            |               |             |
| 112. <i>Pao fangi</i> (Pellegrin & Chevey, 1940)       | -              | +           | -          | -          | NE            | Local       |
| 113. <i>Pao leiurus</i> (Bleeker, 1850)                | -              | +           | -          | +          | LC            | Local       |
| 114. <i>Pao cochichinensis</i> (Steindachner, 1866)    | -              | -           | -          | +          | LC            | Local       |
| <b>23. Loricariidae</b>                                |                |             |            |            |               |             |
| 115. <i>Hypostomus plecostomus</i> (Linnaeus, 1758)    | +              | -           | -          | -          | NE            | Alien       |
| <b>24. Colubridae</b>                                  |                |             |            |            |               |             |
| 116. <i>Enhydrys bocourti</i> (Jan, 1965)              | +              | -           | -          | -          | LC            | Local       |
| Total species richness (116)                           | 70             | 41          | 45         | 65         |               |             |
| Average individuals.year <sup>-1</sup>                 | 8,513.80       | 4,959.40    | 5,614.30   | 3,988.20   |               |             |
| Average biomass (g.year <sup>-1</sup> )                | 186,345.20     | 210,095.30  | 109,195.90 | 61,164.10  |               |             |
| Average biomass (kg.year <sup>-1</sup> )               | 186.3          | 210.1       | 109.2      | 61.2       |               |             |

Remarks: - = 0 individual; + = 1-100 individuals; ++ = 101-1,000 individuals; +++ = 1001-10,000 individuals; CR = Critically endangered; DD = Data deficient; EN = Endangered; LC = Least concern; NT = Near threatened; NE = Not evaluated; VU = Vulnerable.