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The fish fauna of Nee Soon Swamp Forest, Singapore

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Abstract. The Nee Soon Swamp Forest is the last remaining primary freshwater swamp forest in Singapore and contains almost half of its native and threatened freshwater fauna. As the last in-depth fauna study of freshwater fishes in NSSF was published nearly two decades ago, eight series of surveys were carried out over a year to document the species currently present and to update their conservation status. Of the 36 species found, 30 are native to Singapore and six are likely to be introduced from elsewhere in Southeast Asia (4), East Asia (1) and the New World (1). One native species, *Barbodes lateristriga* is documented for the first time in Nee Soon Swamp Forest. Spatial and temporal differences in the mean abundance of fishes found, as well as interesting distribution patterns of freshwater fish in Nee Soon Swamp Forest are crucial in the formulation of conservation strategies to safeguard the current diversity of fish species, many of which are critically endangered or threatened at the national level in the rapidly developing Singapore.

Key words. Nee Soon Swamp Forest, freshwater fish, spatial distribution, temporal distribution, Singapore

INTRODUCTION

The Nee Soon Swamp Forest (NSSF) is located in the northeastern part of the Central Catchment Nature Reserve, bordered by the Upper Seletar Reservoir on the north, Seletar Expressway and Old Upper Thomson Road on the east, Upper and Lower Peirce reservoirs on the south, southern-most tributary of the Upper Seletar Reservoir and the northern-most tributary of the Upper Peirce Reservoir on the west (Fig. 1; Yeo & Lim, 2011). The forest consists of primary and old secondary vegetation, covering an area of approximately 5 km^2 as described in detail by Corner, 1978; Ng & Lim, 1992; and Turner et al., 1996. Occasional floods, waterlogged conditions and forest streams provide specialised microhabitats needed by a high diversity of freshwater organisms (Turner et al., 1996; Ng & Lim, 1997). About 41% of the primary freshwater fish, 59% of the amphibian, 23% of the reptile, 42% of freshwater prawn, 67% of freshwater crab and 30% of the bird species extant to Singapore still persist within this last remaining primary freshwater swamp forest (NSS, 2014; Ng & Lim, 1992; Yeo & Lim, 2011).

Previous studies (Brittan, 1954; Ng & Lim, 1996, 1997) reported that NSSF contains 25 species of native freshwater fishes belonging to 15 families. An introduced species, *Acarichthys heckelii*, native to South America and believed to be imported into Singapore via the ornamental fish trade has also been found in one of the streams but the species has not established itself in Nee Soon Swamp Forest due to high acidity of the stream water and lack of suitable substratum (Tan & Lim, 2008; Liew & Tan, 2008; Liew et al., 2013). Ng & Lim (1997) noted that NSSF has been suffering from possible excess drainage, which may lead to the extinction of certain fish species in the long run such as *Pangio muraeniformis* (*Pangio shelfordii* in Ng & Lim, 1997), *Nemacheilus selangoricus*, *Silurichthys hasselti*, *Parakysis longirostris* and *Pseudomystus leiacanthus* (*P. rugosus* in Ng & Lim, 1997) due to their fastidious habitat requirements and small populations. Information on the freshwater fish species found in Nee Soon Swamp Forest has not been updated since the last extensive survey done between 1992 and 1997, except for the rediscovery of a species of freshwater goby *Pseudogobiopsis oligactis* that had previously been presumed extinct within Singapore (Tan & Lim, 2011). The most recent record of an Asian Arowana *Scleropages formosus* found at the outskirts of NSSF (Tan & Ng, 2014) was in fact outside the boundary of NSSF. Giam et al. (2011) concluded based on ecological modelling that extinctions of freshwater fish in Singapore appear to be driven by loss of entire populations following habitat conversions and species historically restricted to single drainages within Singapore were more likely to go extinct. Thus, local conservation efforts should focus on the species that are currently restricted in Singapore to Nee Soon Swamp Forest, which holds the last remaining patch of primary freshwater swamp forest in Singapore.

This study documents the fish species inhabiting the streams in Nee Soon Swamp Forest and sheds light on potential threats that the native fish species may be facing. Original observations on the behaviour of the fishes and their natural history are also recorded when possible. It aims to provide

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Fig. 1. Location of Nee Soon Swamp Forest on Singapore Island (shaded area).

quantitative data on the species found in Nee Soon Swamp Forest area needed to assess the status of these as a first step towards their conservation.

MATERIAL AND METHODS

Surveys were conducted at 20 sites, where 12 sites involved quantitative sampling and eight sites involved qualitative sampling (Fig. 2). Sites 1–8 were surveyed eight times, between February to March 2013 and September 2013 to March 2014, while sites 9–12 were surveyed four times, between September 2013 and March 2014. Qualitative sampling was conducted once at sites not covered during the quantitative surveys (sites 13–20). Each survey was carried out within 8–12 days. Downstream sites were sampled first before moving to the upstream sites. Sites 1 and 2 are located at the outskirts of NSSF with no canopy cover and moderate water flow. Sites 3 and 4 are in the middle of the swamp forest with slight to moderate forest canopy and deep, open stretches of water converging to large ponds. Sites 5 and 6 are deep in the forest with dense canopy cover and fast flowing water. Sites 7 and 8 are at the upper reaches and form part of a forested trail with dense leaf litter and clear ponds with sandy streambed. Sites 9 and 10 are in the lower swamp forest area with dense canopy cover, slow flowing water and very muddy streambed. Sites 11 and 12 are part of the upper swamp forest with fast flowing water, sandy to clayey substrate and moderate canopy cover (Fig. 3a–f, Fig. 4a–f). Sites 13–16 are along a small, narrow stream

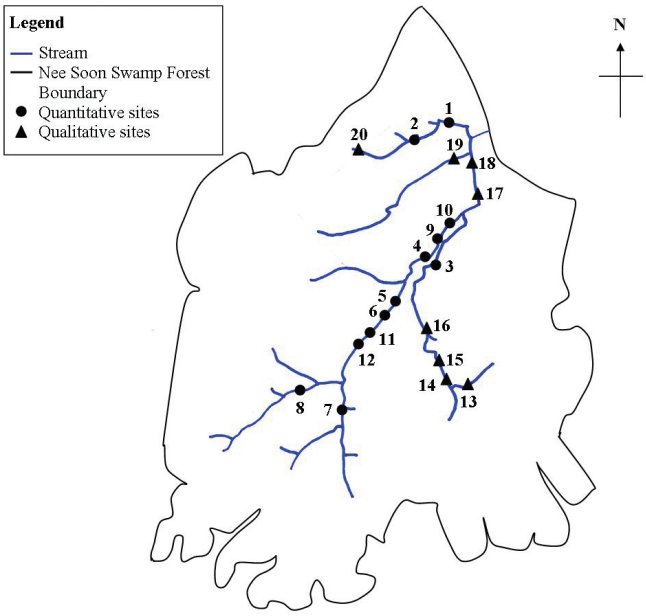

Fig. 2. Map of Nee Soon Swamp Forest with drainage system (blue lines indicate streams), quantitative sampling sites (circles numbered 1–12) and qualitative sampling sites (triangles numbered 13–20).

that leads to the pond at site 3. Sites 17–20 are within close proximity to the military Nee Soon Ranges. Temperature and pH of the streams at each site were measured with a hand held pH meter or HANNA 9829 Multiparameter meter and are summarised in Table 1.

Fig. 3. Streams at Sites 1–6: A, Site 1; B, Site 2; C, Site 3; D, Site 4; E, Site 5; F, Site 6.

Fig. 4. Streams at Sites 7–12: A, Site 7; B, Site 8; C, Site 9; D, Site 10; E, Site 11; F, Site 12.

Table 1. Summary of mean pH and temperature of 16 survey sites.

Site	pH	Temperature/°C
1	5.97	26.3
2	5.45	26.2
3	5.40	26.1
4	5.19	25.3
5	5.01	25.4
6	4.97	25.5
7	4.99	25.6
8	4.75	25.8
9	4.65	25.0
10	4.51	24.8
11	4.54	24.4
12	4.40	24.6
13	6.41	27.4
14	6.54	27.4
15	6.32	27.1
16	5.50	27.0

Quantitative survey. Both hand and trap samplings were used in the fish surveys. Hand sampling involved repetitive sweeping motion against the banks with a tray net (60 × 40 cm, mesh size 0.5 cm) starting from downstream to upstream direction along a stretch of 15–20 metres in the designated sampling site. Banks and vegetation at the stream edge were disturbed by kicking towards the sampling net up to 30 minutes at each site, and fishes caught were kept in a container containing stream water for measurement and identification. Three to five plastic minnow traps (mixture of large with diameter 16.0 cm, and medium with diameter 12.5 cm, mesh size 0.2 cm) were used for the trap sampling at each site. A 2 kg lead weight was secured to each trap using cable ties to ensure that traps were fully submerged in water, with openings facing downstream. Traps were secured to bank vegetation with raffia strings. A mixture of raw pig liver and Yellowstripe scad (Carangidae: *Selaroides leptolepis*) were used as bait in the traps and the traps were collected on the following day. Fishes caught using either method were identified to species level and their standard length (length measured from tip of upper jaw to base of caudal fin) measured using digital vernier calipers before being released to their original environment. The mean standard lengths of individual species are listed in the species accounts to indicate the general size of fishes captured and released in this study.

Qualitative survey. Fish surveys were conducted at sites 13–16 and other ad hoc areas in NSSF using similar hand and/or trap sampling techniques as quantitative surveys except that hand sampling was not timed. After the species were identified, they were released back to their natural habitat. Qualitative sampling was carried out only once at these sites due to the short nature of this study. Despite the time limitation, qualitative data provided more thorough coverage of the spatial distribution of freshwater fish in NSSF.

Data analysis. Data from both quantitative and qualitative surveys were used to map the distribution of freshwater fish at sampling sites 1–16. The Shannon-Weiner index (H') was used to assess species diversity of fishes at each site. The equation for Shannon-Weiner index is as follows:

$H' = -\Sigma(P_i \log[P_i])$, Where P_i = number of individual species / total number of individuals.

One-way analysis of variance (ANOVA) was used to test for differences in the abundance of each fish species between sites and sampling cycles. This generates an overview of the population size on a spatial and temporal scale. For the diversity index and ANOVA analysis, only data from sites 1–8 were used as these sites were surveyed eight times in the study. Sites 9–12 were surveyed only four times and sites 13–16 were surveyed once throughout the study, limiting the robustness of the data for analysis.

Temperature and pH of all the survey sites were also monitored in each sampling session.

SPECIES CHECKLIST

Order Cypriniformes

Family Cyprinidae

***Barbodes banksi* (Herre, 1940)**
(Fig. 5)

Puntius binotatus banksi Herre, 1940: 31.
Puntius binotatus Alfred, 1966: 23; Lim & Ng, 1990: 34.
Puntius banksi Ng & Lim, 1996: 110; 1997: 246.
Systomus banksi Baker & Lim, 2012: 35.
Barbodes banksi Kottelat, 2013: 77.

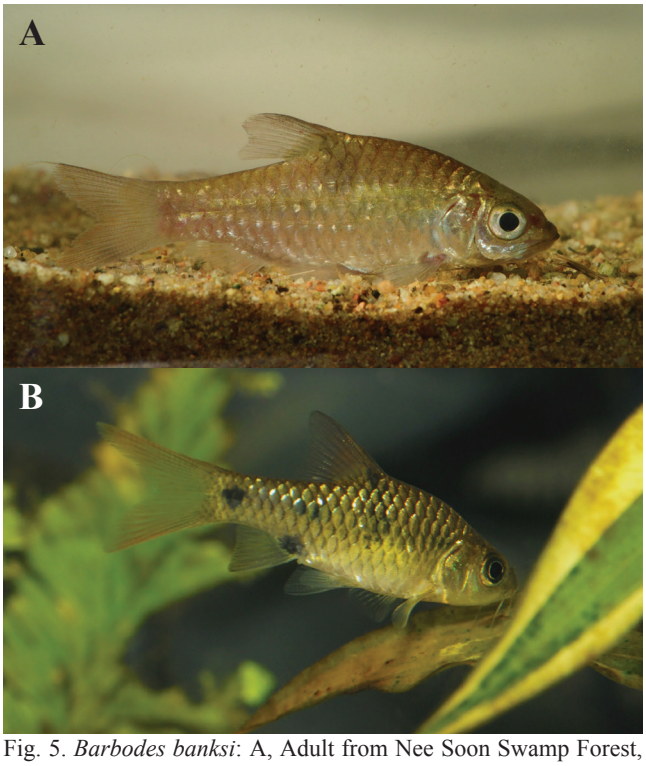

Fig. 5. *Barbodes banksi*: A, Adult from Nee Soon Swamp Forest, 3.8 cm SL; B, Juvenile with scattered black markings, 2.0 cm SL.

Common name. Saddle barb.

Status in Singapore. Native, common, restricted to a few areas.

Status in NSSF. Common, widespread, present in sites 1–11.

Distribution. Malay Peninsula, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Lower Peirce forest and Sime Road forest.

Description. *Barbodes banksi* is commonly found in forest streams and some monsoon drains. The adults are easily recognisable by their rhomboidal body shape and a black inverted triangular patch below the dorsal fin. The body pattern in juvenile fishes differs by having scattered black markings (Fig. 5B) (Lim & Ng, 1990; Baker & Lim, 2012). Individuals recorded in this study have a mean standard length of 3.8 ± 1.3 cm (mean ± standard deviation, n = 121).

Barbodes lateristriga (Valenciennes, in Cuvier & Valenciennes, 1842)
(Fig. 6)

Barbus lateristriga Valenciennes, in Cuvier & Valenciennes, 1842: 161.
Puntius lateristriga Alfred, 1966: 25, pl. 3 fig. 2; Lim & Ng, 1990: 36; Ng & Lim, 1996: 110; 1997:246.
Systomus lateristriga Baker & Lim, 2012: 36.
Barbodes lateristriga Kottelat, 2013: 78.

Common name. Spanner barb or T-barb.

Status in Singapore. Native, rare, restricted to a few areas.

Status in NSSF. Uncommon, restricted to sites 3, 4, 6 and 11.

Distribution. Malay Peninsula, Java, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Lower Peirce forest and Sime Road forest.

Description. *Barbodes lateristriga* is usually recognised by the horizontally orientated 'T' pattern on the body of the fish. Based on current field observations, it is a very fast swimmer which frequents middle to lower waters and very few specimens were obtained via hand sampling. Most of the T-barbs in this survey were caught by trapping and consist of only smaller-sized individuals in deep waters of up to 2 m. Individuals recorded in this study have a mean standard length of 4.4 ± 3.3 cm (n = 26).

Fig. 6. *Barbodes lateristriga* juvenile from Nee Soon Swamp Forest, 3.2 cm SL.

Boraras maculatus (Duncker, 1904)
(Fig. 7)

Rasbora maculata Duncker, 1904: 182, pl. 1 fig. 6; Alfred, 1966: 19; Lim & Ng, 1990: 28.
Boraras maculatus Ng & Lim, 1996: 110; 1997: 246; Lim et al., 2008: 147; Baker & Lim, 2012: 157; Kottelat, 2013: 82.

Fig. 7. *Boraras maculatus* from MacRitchie Forest, 1.9 cm SL

Common name. Malayan pygmy rasbora.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Rare, restricted to site 2.

Distribution. Malay Peninsula and Sumatra. Singapore: Nee Soon Swamp Forest, Sime Road forest and MacRitchie Reservoir.

Description. The colourful *Boraras maculatus* is the smallest rasborine in Singapore. It is very elusive and usually found in shallow and acidic waters (Lim & Ng, 1990). The Malayan pygmy rasbora was observed in this study to be very sensitive to water temperature and a slight increase in this can lead to its demise. It was only recorded from areas with dense canopy coverage in the forested areas. Individuals recorded in this study have a mean standard length of 1.4 ± 0.1 cm (n = 53).

Desmopuntius hexazona (Weber & de Beaufort, 1912)
(Fig. 8)

Barbus (*Barbodes*) *hexazona* Weber & de Beaufort, 1912: 527, pl. 11 fig. 2.
Puntius pentazona johorensis Alfred, 1966: 26.
Puntius johorensis Lim & Ng, 1990: 37.
Puntius hexazona Ng & Lim, 1996: 110; 1997: 246.
Systomus hexazona Lim et al., 2008: 146; Baker & Lim, 2012: 157.
Desmopuntius hexazona Kottelat, 2013: 97.

Fig. 8. *Desmopuntius hexazona* from Nee Soon Swamp Forest, 2.6 cm SL.

Common name. Six-banded tiger barb.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Uncommon, Restricted to sites 3–7.

Distribution. Sumatra and Borneo. Singapore: Nee Soon Swamp Forest.

Description. *Desmopuntius hexazona* can be easily distinguished from other tiger barbs by the presence of six bars on its body (Lim & Ng, 1990). The first bar always passes through its eye and the last bar is found at the base of the caudal fin. The other bars are evenly spaced between these two. The six-banded tiger barb was found in sites with shallow and muddy waters. This uncommon species is the only native tiger barb from the genus *Desmopuntius* recorded from Singapore. Individuals recorded in this study have a mean standard length of 2.4 ± 0.4 cm (n = 32).

***Osteochilus vittatus* (Valenciennes, in Cuvier & Valenciennes, 1842)**
(Fig. 9)

Rohita vittata Valenciennes, in Cuvier & Valenciennes, 1842: 267.
Osteochilus hasselti Ng & Lim, 1996: 116; Baker & Lim, 2012: 164.
Osteochilus vittatus Ng & Tan, 2010: 101, fig. 6a; Kottelat, 2013: 136.

Common name. Bony-lipped barb.

Status in Singapore. Introduced, common, restricted to a few areas.

Fig. 9. *Osteochilus vittatus* from Nee Soon Swamp Forest, 4.8 cm SL.

Status in NSSF. Uncommon, restricted to site 1.

Distribution. Indochina, Thailand, Malay Peninsula, Indonesia and Borneo. Singapore: Nee Soon Swamp Forest, Sime Road forest, Upper Seletar Reservoir, Lower Seletar Reservoir, Upper Peirce Reservoir and Lower Peirce Reservoir (Ng & Tan, 2010; Tan, 2013a, b).

Description. *Osteochilus vittatus* has a very wide distribution in Southeast Asia and is an introduced species in Singapore possibly through introduction of raw water from Malaysia (Ng & Lim, 1996; Ng & Tan, 2010). The bony-lipped barb is similar to the saddle barb in body shape but has a much longer dorsal fin with reddish colouration and a round blotch on the caudal peduncle. This species was only recorded at the outskirts of NSSF linking to Upper Seletar Reservoir. Individuals recorded in this study have a mean standard length of 3.1 ± 1.1 cm (n = 25).

Puntigrus tetrazona (Bleeker, 1855)
(Fig. 10)

Capoeta tetrazona Bleeker, 1855: 262.
Puntius tetrazona Lim & Ng, 1990: 38; Ng & Lim, 1996: 115.
Systomus tetrazona Ng & Tan, 2010: 101, fig. 6c; Baker & Lim, 2012: 164.
Puntigrus tetrazona Kottelat, 2013: 147.

Fig. 10. *Puntigrus tetrazona* from MacRitchie forest, 2.5 cm SL.

Common name. Tiger barb.

Status in Singapore. Introduced, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Lower Seletar Reservoir, Upper Seletar Reservoir, Lower Peirce Reservoir, Upper Peirce Reservoir, MacRitchie Reservoir, Murai Reservoir, Pulau Tekong Reservoir and Tengeh Reservoir (Ng & Tan, 2010).

Description. *Puntigrus tetrazona* is a common species in the aquarium trade and an introduced species to Singapore from Sumatra (Lim & Ng, 1990; Ng & Tan, 2010). Compared to the native six-banded tiger barb, it has a deeper body with four black bars and red fins. Ng & Tan (2010) discussed variation in the colour pattern of this species and suggested

that *P. partipentazona* and *P. tetrazona* reported previously from Singapore were both *P. tetrazona* due to the absence of a distinct black blotch at the base of the dorsal fin. This species was only recorded at the outskirts of NSSF linking to Upper Seletar Reservoir. The only individual recorded in this study has a standard length of 3.0 cm.

Rasbora borapetensis Smith, 1934
(Fig. 11)

Rasbora borapetensis Smith, 1934: 302; Lim & Ng, 1990: 31; Ng & Lim, 1996: 115; Ng & Tan, 2010: 101, fig. 6b; Baker & Lim, 2012: 164; Kottelat, 2013: 151.

Fig. 11. *Rasbora borapetensis* from MacRitchie Forest, 2.3 cm SL.

Common name. Red-tailed rasbora.

Status in Singapore. Introduced, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. Laos, Vietnam, Cambodia, Thailand and Malay Peninsula. Singapore: Nee Soon Swamp Forest, MacRitchie Reservoir and Lower Seletar Reservoir (Ng & Tan, 2010).

Description. *Rasbora borapetensis* is morphologically similar to *Rasbora einthovenii* but the lateral black stripe does not pass through its eye or caudal fin. The presence of bright red colouration at the base of the caudal fin is another distinguishing feature. This species is imported from other parts of Southeast Asia to Singapore in large quantities in the aquarium trade and its hardy nature might have allowed it to establish in local streams (Lim & Ng, 1990). This species was only recorded at the outskirts of NSSF linking to the Upper Seletar Reservoir. Individuals recorded in this study have a mean standard length of 2.3 ± 0.5 cm (n = 2).

Rasbora einthovenii (Bleeker, 1851)
(Fig. 12)

Leuciscus einthovenii Bleeker, 1851a: 434.
Rasbora einthovenii Alfred, 1966: 18, pl. 2 fig.3; Lim & Ng, 1990: 29; Ng & Lim, 1996: 111; 1997: 246; Baker & Lim, 2012: 34; Kottelat, 2013: 152.

Common name. Einthoven's rasbora.

Fig. 12. *Rasbora einthovenii* from Nee Soon Swamp Forest, 3.8 cm SL.

Status in Singapore. Native, common, restricted to a few areas.

Status in NSSF. Common, widespread, present in all sites except site 11.

Distribution. Malay Peninsula, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Tengeh Reservoir, Punggol Reservoir and Pulau Tekong.

Description. *Rasbora einthovenii* is found only in shallow, acidic forest streams which are slow flowing. It has a prominent yellowish bronze body and a black lateral stripe which spans across the entire length of the body from the tip of its lower jaw, through its eye to the end of the caudal fin. Individuals recorded in this study have a mean standard length of 2.6 ± 0.8 cm (n = 233).

Rasbora elegans Volz, 1903
(Fig. 13)

Rasbora elegans Volz, 1903: 558; Alfred, 1966: 19, pl. 2 fig. 4; Lim & Ng, 1990: 26; Ng & Lim, 1996: 111; 1997: 246; Baker & Lim, 2012: 35; Kottelat, 2013: 152.

Common name. Two-spot rasbora.

Status in Singapore. Native, common, restricted to a few areas.

Fig. 13. *Rasbora elegans* from Nee Soon Swamp Forest, 3.2 cm SL.

Status in NSSF. Common, widespread, present in all sites except site 11.

Distribution. Malay Peninsula, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Lower Peirce forest, Sime Road forest and Upper Seletar Reservoir.

Description. The two spots on the slender-bodied *Rasbora elegans* are highly variable, with the spots on some fishes being more prominent than others (Lim & Ng, 1990; Baker & Lim, 2012). This fish is a fast swimmer and usually occurs in groups. It is the fourth most abundant fish in Nee Soon Swamp Forest (Fig. 44). Individuals recorded in this study have a mean standard length of 3.3 ± 1.8 cm (n = 414).

Trigonostigma heteromorpha (Duncker, 1904)
(Fig. 14)

Rasbora heteromorpha Duncker, 1904: 182, pl. 1 fig. 5; Brittan, 1954a: 152; 1954b: 187, fig. 44; Alfred, 1966: 19; Lim & Ng, 1990: 32; Ng & Lim, 1996: 111; 1997: 246.
Trigonostigma heteromorpha Lim et al., 2008: 147; Baker & Lim, 2012: 36; Kottelat, 2013: 170.

Fig. 14. *Trigonostigma heteromorpha* from Nee Soon Swamp Forest, 2.1 cm SL.

Common name. Harlequin rasbora.

Status in Singapore. Native, endangered, restricted to a few areas.

Status in NSSF. Common, widespread, present in sites 2–12.

Distribution. Malay Peninsula and Sumatra. Singapore: Nee Soon Swamp Forest and Sime Road forest.

Description. *Trigonostigma heteromorpha* is commonly seen swimming in small schools at the middle and surface of shaded forest streams. It has a prominent black triangular blotch on the side of its body and bright red fins. The attractiveness of this fish and its popularity in the aquarium trade has also led to illegal poaching, resulting in a decline in its population in Singapore (Lim et al., 2008). Although the national status of this fish is "Endangered" due to its restricted range to only forest streams in the Central Catchment Nature Reserve, it is the most abundant species in Nee Soon Swamp Forest (Fig. 44). Details on the conservation status of this species will be elaborated in the discussions. Individuals recorded in this study have a mean standard length of 1.9 ± 0.5 cm (n = 1099).

Family Cobitidae

Pangio muraeniformis (de Beaufort, 1933)
(Fig. 15)

Acanthophthalmus (*Cobitophis*) *muraeniformis* de Beaufort, 1933: 32.
Acanthophthalmus muraeniformis Alfred, 1966: 30, pl. 4.
Pangio sheldfordii Ng & Lim, 1996: 111; 1997: 246.
Pangio muraeniformis Lim & Ng, 1990: 56; Lim et al., 2008: 148; Baker & Lim, 2012: 37; Kottelat, 2013: 183.

Fig. 15. *Pangio muraeniformis* from Nee Soon Swamp Forest, 5.8 cm SL.

Common name. Spotted eel-loach.

Status in Singapore. Native, endangered, restricted to a few areas.

Status in NSSF. Common, widespread, present in all sites except site 8.

Distribution. Malay Peninsula and Indonesia (Riau islands). Singapore: Nee Soon Swamp Forest and Upper Seletar Reservoir.

Description. *Pangio muraeniformis* has an extremely slender, eel-like body that is usually yellowish-brown with numerous black blotches and a slightly emarginated caudal fin (Baker & Lim, 2012). It is a bottom dweller often residing in dense leaf litter and can only be caught by heavy disturbance of the muddy substrate in streams. Individuals recorded in this study have a mean standard length of 2.9 ± 1.1 cm (n = 183).

Family Nemacheilidae

Nemacheilus selangoricus **Duncker, 1904**
(Fig. 16)

Nemacheilus selangoricus Duncker, 1904: 175; Alfred, 1966: 31, pl. 5 fig. 7; Lim & Ng, 1990: 53; Ng & Lim, 1996: 111;

1997: 246; Lim et al., 2008: 148; Baker & Lim, 2012: 37; Kottelat, 2013: 202.

Fig. 16. *Nemacheilus selangoricus* from Nee Soon Swamp Forest, 4.8 cm SL.

Common name. Grey-banded sand loach.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Common, widespread, present in sites 3–12.

Distribution. Sumatra and Borneo. Singapore: Nee Soon Swamp Forest.

Description. *Nemacheilus selangoricus* has a cylindrical body with approximately 8 to 12 grey bars, three pairs of short barbels at the subterminal mouth and a forked caudal fin (Baker & Lim, 2012). Unlike the spotted eel-loach, the grey-banded sand loach prefers sandy substrates and can be seen resting on the shaded stream bed in some occasions. While it is easy to obtain spotted eel-loaches by hand catching in this study, most grey-banded sand loaches were caught by traps. Individuals recorded in this study have a mean standard length of 4.4 ± 0.8 cm (n = 252).

Order Siluriformes

Family Akysidae

Parakysis longirostris Ng & Lim, 1995
(Fig. 17)

Parakysis verrucosus Lim & Ng, 1990: 65.
Parakysis longirostris Ng & Lim, 1995: 262, fig. 8; Ng & Lim, 1996: 112, fig. 3; 1997: 247; Lim et al., 2008: 150; Baker & Lim, 2012: 157; Kottelat, 2013: 220.

Common name. Little warty catfish.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Uncommon, widespread, present in sites 2–7 and 9–11.

Distribution. Malaysia, Indonesia (Pulau Bintan). Singapore: Nee Soon Swamp Forest.

Fig. 17. *Parakysis longirostris* from Nee Soon Swamp Forest, 2.9 cm SL.

Description. The solitary *Parakysis longirostris* has a distinctive cryptic coloration comprising of irregular black patches on a brown body. *Parakysis longirostris* usually reside in thick clumps of vegetation or in leaf litter at the side of a flowing stream (Lim & Ng, 1990; Ng & Lim, 1995). Individuals recorded in this study have a mean standard length of 3.2 ± 0.5 cm (n = 12).

Family Siluridae

Silurichthys hasseltii Bleeker, 1858
(Fig. 18)

Silurichthys hasseltii Bleeker, 1858: 270; Alfred, 1966: 34, pl. 6 fig. 1; Lim & Ng, 1990: 58; Ng & Lim, 1996: 111, fig. 1; 1997: 246; Lim et al, 2008: 149; Baker & Lim, 2012: 38; Kottelat, 2013: 238.

Common name. Hasselt's leaf catfish.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Rare, present in site 3 and sites 6–8.

Distribution. Malaysia, Java and Sumatra. Singapore: Nee Soon Swamp Forest, Upper Seletar Reservoir and MacRitchie Reservoir.

Description. *Silurichthys hasseltii* has a slender body and a long anal fin that is fused to the elongated tail fin. It has

Fig. 18. *Silurichthys hasseltii* from Nee Soon Swamp Forest, 5.3 cm SL.

two pairs of barbels differing in length and a much reduced dorsal fin. The Hasselt's leaf catfish is nocturnal and usually hides under submerged leaf litter during the day (Lim & Ng, 1990). This fish is now very rare in Singapore and was recorded only four times throughout the survey. Individuals recorded in this study have a mean standard length of 5.6 ± 2.5 cm (n = 5).

Family Clariidae

***Clarias leiacanthus* Bleeker, 1851**
(Fig. 19)

Clarias teijsmanni Bleeker, 1851b: 344; Alfred, 1966: 38; Lim & Ng, 1990: 63; Ng & Lim, 1996: 112; 1997: 247.
Clarias leiacanthus Baker & Lim, 2012: 39; Kottelat, 2013: 243.

Fig. 19. *Clarias leiacanthus* with vertical rows of yellow spots on the sides from Nee Soon Swamp Forest, 10.0 cm SL.

Common name. Forest walking catfish.

Status in Singapore. Native, rare, restricted to a few areas .

Status in NSSF. Uncommon, widespread, present in all 12 sites.

Distribution. Malay Peninsula, Java, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest and Central Catchment Nature Reserve.

Description. *Clarias leiacanthus* can be distinguished by a black or dark brown body with vertical rows of yellow spots on the sides, four pairs of barbels, a long dorsal fin and anal fin separated from the caudal fin. Unlike the common walking catfish, this species has a wide gap between the back margin of exposed bony plates on its head and the origin of dorsal fin (Lim & Ng, 1990; Baker & Lim, 2012). Based on field observations in this study, the gap between the bony plates and dorsal fin origin ranged from 1.6 cm to 2.7 cm in the adult specimens (5.9 to 31.5 cm SL, n = 28). Individuals recorded in this study have a mean standard length of 18.4 cm ± 7.6 cm (n = 28).

***Clarias nieuhofii* Valenciennes, in Cuvier & Valenciennes, 1840**
(Fig. 20)

Clarias nieuhofii Valenciennes, in Cuvier & Valenciennes, 1840: 386; Lim et al, 2008: 149; Baker & Lim, 2012: 39; Lim, 2013: 92; Kottelat, 2013: 244.

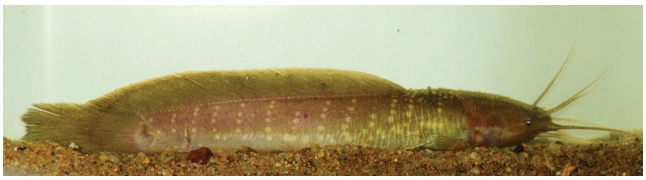

Fig. 20. *Clarias nieuhofii* with long dorsal fin and anal fin fused to the tail fin in Nee Soon Swamp Forest, 16.0 cm SL. Dorsal and caudal fins are damaged but recovered.

Common name. Slender walking catfish.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Rare, restricted to sites 7, 8 and outskirts of NSSF (Lim, 2013).

Distribution. Malaysia, Java, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest and Pulau Tekong.

Description. *Clarias nieuhofii* can be distinguished from *C. leiacanthus* by its much more slender body even in juveniles and its long dorsal fin and anal fin that are partially fused to the caudal fin. Based on field observations in this study, the body depth (dorsal to ventral surface of the fish excluding fins) of the slender walking catfish is almost equivalent to the sum of the depth of the dorsal and anal fins. The body depth of the forest walking catfish is about twice the measurement. This species is less common than the forest walking catfish, being recorded in only two sites throughout the survey. Individuals recorded in this study have a mean standard length of 32.0 ± 1.6 cm (n = 2).

Family Bagridae

***Pseudomystus leiacanthus* (Weber & de Beaufort, 1912)**
(Fig. 21)

Leiocassis leiacanthus Weber & de Beaufort, 1912: 536.
Pseudomystus cf. *siamensis* Ng & Lim, 1996: 112, fig. 2.
Pseudomystus rugosus Ng & Lim, 1997: 247.
Pseudomystus leiacanthus Lim et al., 2008: 150; Baker & Lim, 2012: 157; Kottelat, 2013: 265.

Common name. Dwarf bumblebee catfish.

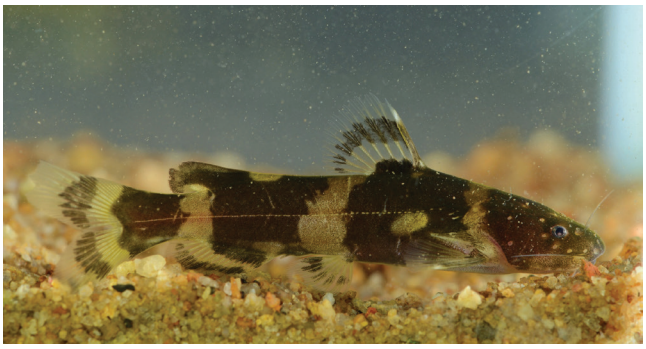

Fig. 21. *Pseudomystus leiacanthus* from Nee Soon Swamp Forest, 3.1 cm SL.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Rare, restricted to sites 3 and 5.

Distribution. Malaysia, Sumatra (Riau islands). Singapore: Nee Soon Swamp Forest.

Description. Based on field observations in this study, *Pseudomystus leiacanthus* can be identified by its interspersed black and white body patterns and the caudal fin lobes that are usually rounded. The dwarf bumblebee catfish is extremely rare and has only been recorded twice at site 3 and site 5 respectively throughout the entire survey. It was found residing in submerged bank vegetation. Individuals recorded in this study have a mean standard length of 3.1 ± 0.9 cm (n = 2).

Order Beloniformes

Family Zenarchopteridae

Dermogenys collettei Meisner, 2001
(Fig. 22)

Dermogenys pusillus Alfred, 1966: 41; Lim & Ng, 1990: 70; Ng & Lim, 1996: 113; 1997: 247.
Dermogenys collettei Meisner, 2001: 238, fig. 37; Baker & Lim, 2012: 40.

Fig. 22. *Dermogenys collettei* from Nee Soon Swamp Forest, 3.2 cm SL. Dorsal fin (red arrow) of *Dermogenys collettei* begins after anal fin.

Common name. Malayan pygmy halfbeak.

Status in Singapore. Native, common, widespread.

Status in NSSF. Uncommon, restricted to site 1.

Distribution. Malay Peninsula, Borneo and Sumatra. Singapore: Nee Soon Swamp Forest, Sungei Kranji, stream along Woodlands Road, Punggol Reservoir, Sime Road forest, Upper Seletar Reservoir and Lorong Banir.

Description. *Dermogenys collettei* differs from *Hemirhamphodon pogonognathus* by its shorter and more robust body and the absence of a fleshy tip on the anterior end of the elongated lower jaw. This species is usually found in small schools at the surface of exposed streams that are much higher in light intensity (Lim & Ng, 1990 as *Dermogenys pusillus*). Throughout the entire survey, *Dermogenys collettei* was only found at the outskirts of NSSF linking to the Upper Seletar Reservoir. Individuals recorded in this study have a mean standard length of 3.0 ± 0.8 cm (n = 198).

Hemirhamphodon pogonognathus (Bleeker, 1853)
(Fig. 23)

Hemiramphus pogonognathus Bleeker, 1853: 193.
Hemirhamphodon pogonognathus Alfred, 1966: 41; Lim & Ng, 1990: 71; Ng & Lim, 1996: 112; 1997: 247; Baker & Lim, 2012: 40; Kottelat, 2013: 294.

Fig. 23. *Hemirhamphodon pogonognathus* from Nee Soon Swamp Forest, 6.7 cm SL. Dorsal fin (red arrow) of *Hemirhamphodon pogonognathus* begins before anal fin.

Common name. Malayan forest halfbeak.

Status in Singapore. Native, common, restricted to a few areas.

Status in NSSF. Common, widespread, present in all 12 sites.

Distribution. Malay Peninsula, Sumatra and Borneo. Singapore: Central Catchment area.

Description. *Hemirhamphodon pogonognathus* can be easily identified by its long, slender body and more colourful body patterns. Its elongated lower jaw is reddish on the underside with a fleshy tip that curves downwards. *Hemirhamphodon pogonognathus* differs from *Dermogenys collettei* in having its dorsal fin origin anterior to the anal fin origin vs. posterior to the anal fin origin in *D. collettei* (Lim & Ng, 1990). The Malayan forest halfbeak is commonly seen in schools on the surface of forested streams. This species is the second most abundant in Nee Soon Swamp Forest (Fig. 44). Individuals recorded in this study have a mean standard length of 4.1 ± 1.3 cm (n = 761).

Order Cyprinodontiformes

Family Aplocheilidae

Aplocheilus panchax (Hamilton, 1822)
(Fig. 24)

Esox panchax Hamilton, 1822: 211, 380, pl. 3 fig. 69.
Aplocheilus panchax Alfred, 1966: 42; Lim & Ng, 1990: 72; Ng & Lim, 1996: 112; 1997: 247; Baker & Lim, 2012: 41; Kottelat, 2013: 299.

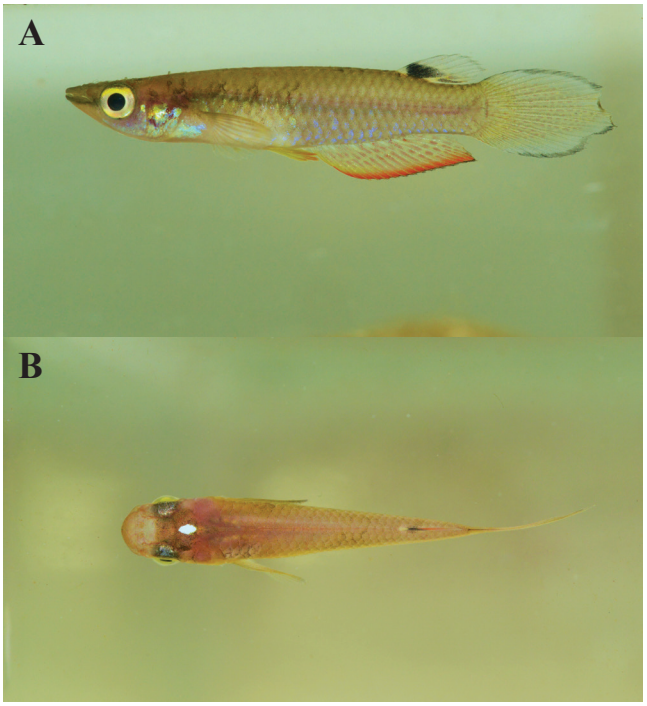

Fig. 24. *Aplocheilus panchax*: A, from Nee Soon Swamp Forest, 2.3 cm SL; B, Prominent white spot on top of its head.

Common name. Whitespot.

Status in Singapore. Native, common, widespread.

Status in NSSF. Rare, restricted to site 2.

Distribution. India, Indochina, Malaysia and western Indonesia. Singapore: Nee Soon Swamp Forest, Senoko, Botanic Gardens, Mandai Road, Sungei Kranji, Pulau Tekong, Pulau Ubin and various reservoirs.

Description. *Aplocheilus panchax* has a prominent shiny white spot on top of its head between the eyes (Fig. 24). There is a black patch in the middle of its dorsal fin and a black stripe along the lower jaw. The whitespot can be found in both freshwater and brackish water (Baker & Lim, 2012). This species was only recorded from a small, shallow and exposed stream draining into the water at the outskirts of NSSF. Individuals recorded in this study have a mean standard length of 2.6 ± 0.5 cm (n = 8).

Family Poeciliidae

Poecilia sphenops Valenciennes, in Cuvier & Valenciennes, 1846
(Fig. 25)

Poecilia sphenops Valenciennes, in Cuvier & Valenciennes, 1846: 130, pl. 525–526; Lim & Ng, 1990: 80; Ng & Lim, 1996: 116; 1997: 257; Ng & Tan, 2010: 106, fig. 10c; Kottelat, 2013: 300.
Mollienisia sphenops Alfred, 1966: 44.

Fig. 25. *Poecilia sphenops* from Nee Soon Swamp Forest, 1.7 cm SL.

Common name. Common molly, Mexican molly.

Status in Singapore. Introduced, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. Southern Mexico and Guatemala. Singapore: Nee Soon Swamp Forest, Bedok Reservoir, Lower Seletar Reservoir, and MacRitchie Reservoir (Ng & Tan, 2010).

Description. *Poecilia sphenops* has a greyish-silver coloration in the wild form. Unlike the lesser sailfin molly, the common molly does not possess large, sail-like dorsal fins and is less colourful. Originating from southern Mexico, it is frequently sold as an aquarium fish and as food for other predatory fish, through which it might have been introduced into the reservoirs (Ng & Tan, 2010). Large populations can be found in rural streams, canals, drains and ponds (Lim & Ng, 1990). Like most introduced species, this fish was only recorded at the outskirts of NSSF linking to the Upper Seletar Reservoir. The only individual recorded in this study has a standard length of 1.7 cm.

Order Synbranchiformes

Family Synbranchidae

Monopterus javanensis La Cepède, 1800
(Fig. 26)

Monopterus javanensis La Cepède, 1800: 139; Kottelat, 2013: 308.
Monopterus albus Lim & Ng, 1990: 84; Ng & Lim, 1996: 114; 1997: 247; Baker & Lim, 2012: 42.

Fig. 26. *Monopterus javanensis* from Nee Soon Swamp Forest, 10.5 cm SL

Common name. Sunda swamp eel.

Status in Singapore. Native, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. Southeast Asia. Singapore: Nee Soon Swamp Forest, various areas including reservoirs and canals.

Description. *Monopterus javanensis* has a very slender body with a long, pointed tail. This snake-like species can grow up to 40 cm in total length and is often characterised by its large mouth, very small eyes and a single gill slit across the throat. The Sunda swamp eel is usually found in dense vegetation in the day and active at night (Lim & Ng, 1990; Baker & Lim, 2012). Although an adaptable species, it was only found at the outskirts of NSSF linking to the Upper Seletar Reservoir. Individuals recorded in this study have a mean standard length of 8.8 cm ± 2.4 cm (n = 2).

Family Mastacembelidae

***Macrognathus maculatus* (Cuvier, in Cuvier & Valenciennes, 1832)**
(Fig. 27)

Mastacembelus maculatus Cuvier, in Cuvier & Valenciennes, 1832: 461; Alfred, 1966: 58.
Macrognathus maculatus Lim & Ng, 1990: 86; Ng & Lim, 1996: 114; 1997: 247; Lim et al, 2008: 153; Baker & Lim, 2012: 157; Kottelat, 2013: 311.

Common name. Buff-backed spiny-eel.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Uncommon, widespread, present in all 12 sites.

Fig. 27. *Macrognathus maculatus* from Nee Soon Swamp Forest, 3.9 cm SL.

Distribution. Vietnam, Cambodia, Malay Peninsula, Sarawak and Indonesia. Singapore: Nee Soon Swamp Forest.

Description. *Macrognathus maculatus* can be identified by its eel-like body and a snout modified into a long proboscis with tube-like nostrils. This strictly nocturnal species is a bottom dweller which usually hides in dense vegetation or leaf litter during the day (Lim & Ng, 1990). Unlike the Sunda swamp eel, the Buff-backed spiny-eel has a more prominent dorsal fin and a row of spines on its dorsum. Individuals recorded in this study have a mean standard length of 4.0 ± 1.3 cm (n = 24).

Order Perciformes

Family Ambassidae

***Parambassis siamensis* (Fowler, 1937)**
(Fig. 28)

Chanda siamensis Fowler, 1937: 230, fig. 228.
Chanda sp. Lim & Ng, 1990: 118.
Parambassis siamensis Ng & Lim, 1996: 117; 1997: 257; Ng & Tan, 2010: 106, fig. 11a; Kottelat, 2013: 322.

Fig. 28. *Parambassis siamensis* from Nee Soon Swamp Forest, 3.4 cm SL.

Common name. Indochinese glass-perchlet.

Status in Singapore. Introduced, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. Thailand, Malay Peninsula and Java. Singapore: Nee Soon Swamp Forest, Upper Peirce Reservoir, Lower Peirce Reservoir, Kranji Reservoir (Ng & Lim, 1996), Upper Seletar Reservoir, Lower Seletar Reservoir, MacRitchie Reservoir, Murai Reservoir and Jurong Lake (Ng & Tan, 2010).

Description. *Parambassis siamensis* can be identified by its large eyes, translucent deep body and forked caudal fin. In Singapore, it has been recorded from reservoirs possibly introduced through raw water from Malaysia (Ng & Tan, 2010). The Indochinese glass-perchlet frequents mid waters and usually hides in dense clumps of aquatic vegetation. This fish was only recorded at the outskirts of NSSF linking to the Upper Seletar Reservoir. Individuals recorded in this study have a mean standard length of 2.3 ± 0.1 cm (n = 2).

Family Eleotridae

Oxyeleotris marmorata (Bleeker, 1852)
(Fig. 29)

Eleotris marmorata Bleeker, 1852: 424.
Oxyeleotris marmorata Lim & Ng, 1990: 112; Ng & Lim, 1996: 113; 1997: 247; Baker & Lim, 2012: 44; Kottelat, 2013: 395.

Fig. 29. *Oxyeleotris marmorata* from Nee Soon Swamp Forest, 2.7 cm SL.

Common name. Soon hock, or marbled goby.

Status in Singapore. Native, common, widespread.

Status in NSSF. Uncommon, restricted to sites 1–3.

Distribution. Indochina, Malay Peninsula, Sumatra, Borneo and the Philippines. Singapore: Jurong Lake, Jalan Kayu, Central Catchment Nature Reserve, and many other locations.

Description. *Oxyeleotris marmorata* is easily recognised by the cylindrical cross-section of its body, the presence of marbled dark brown blotches and three irregular dark brown bars at the posterior part of its body (Baker & Lim, 2012). Its cryptic coloration provides good camouflage in the submerged bank vegetation, as this species is an ambush predator. Individuals recorded in this study have a mean standard length of 3.4 ± 1.6 cm (n = 52).

Family Gobinellidae

Pseudogobiopsis oligactis (Bleeker, 1875)
(Fig. 30)

Gobiopsis oligactis Bleeker, 1875: 113.
Stigmatogobius poicilosoma Alfred, 1966: 47.
Pseudogobiopsis oligactis Ng & Lim, 1996: 113; 1997: 254; Tan & Lim, 2011: 363; Baker & Lim, 2012: 158.
Pseudobiopsis [sic] *oligactis* Kottelat, 2013: 97.

Common name. Bigmouth stream goby.

Status in Singapore. Native, uncommon, widespread.

Status in NSSF. Uncommon, restricted to sites 1 and 2.

Fig. 30. *Pseudogobiopsis oligactis* from Nee Soon Swamp Forest, 3.1 cm SL.

Distribution. Indo-Malay Archipelago from Thailand to Indonesia. Singapore: Nee Soon Swamp Forest.

Description. *Pseudogobiopsis oligactis* was thought to be locally extinct until its rediscovery in 2010 (Tan & Lim, 2011). It was collected from a stream that drains from the north-eastern part of Nee Soon Swamp Forest and feeds into the Lower Seletar Reservoir. The habitat where the goby was found in was relatively exposed and had clean flowing water over a sandy or clayey substrate (Tan & Lim, 2011). Individuals recorded in this study have a mean standard length of 2.0 ± 0.4 cm (n = 18).

Rhinogobius giurinus (Rutter, 1897)
(Fig. 31)

Gobius giurinus Rutter, 1897: 86.
Stigmatogobius poecilosoma Lim & Ng, 1990: 115.
Rhinogobius cf. *giurinus* Ng & Lim, 1996: 117; 1997: 257.
Rhinogobius giurinus Ng & Tan, 2010: 112, fig. 16c; Kottelat, 2013: 425.

Common name. Barcheek goby.

Status in Singapore. Introduced, common, widespread.

Status in NSSF. Uncommon, restricted to sites 1, 2 and 10.

Distribution. Western Pacific from China to Japan. Singapore: Nee Soon Swamp Forest, Upper Peirce Reservoir, Lower Peirce Reservoir, Upper Seletar Reservoir and Lower Seletar Reservoir (Ng & Tan, 2010).

Fig. 31. *Rhinogobius giurinus* from Nee Soon Swamp Forest, 3.2 cm SL.

Description. *Rhinogobius giurinus* is an introduced species from China (Ng & Tan, 2010). It is usually found hiding among the dense bushes of *Hydrilla verticillata* at the outskirts of NSSF and occurs at a much higher abundance than *Pseudogobiopsis oligactis* with a ratio of 3 to 1 based on hand and trap samplings in this study (N = 64). Generally *Rhinogobius giurinus* is more colourful on the head and fins (especially in males) whereas *Pseudogobiopsis oligactis* is dull and has a bulkier head (especially in mature males). Based on field observations in this study, markings below the eyes of *Pseudogobiopsis oligactis* are usually a diagonally oriented "T" pattern, while that of the *Rhinogobius giurinus* are usually diagonal bars. Individuals recorded in this study have a mean standard length of 1.7 ± 0.3 cm (n = 64).

Family Anabantidae

Anabas testudineus (Bloch, 1792)
(Fig. 32)

Anthias testudineus Bloch, 1792: 121, pl. 322.
Anabas testudineus Alfred, 1966: 48; Lim & Ng, 1990: 90; Ng & Lim, 1996: 113; 1997: 247; Baker & Lim, 2012: 44; Kottelat, 2013: 447.

Fig. 32. *Anabas testudineus* from Nee Soon Swamp Forest, 7.6 cm SL.

Common name. Asian climbing perch.

Status in Singapore. Native, common, widespread.

Status in NSSF. Rare, restricted to site 1.

Distribution. India, East Asia, Indochina, Malaysia, Indonesia and the Philippines. Singapore: Central Catchment area and Sungei Buloh Wetland Reserve.

Description. *Anabas testudineus* has a blunt head and stocky body. The posterior edges of its gills are serrated and the anterior two-thirds of its dorsal fin are spiny rays. The body of the Asian climbing perch is olive-grey with inconspicuous blackish bars. This species is capable of surviving short periods out of water by breathing air. It can be found in forest streams and ponds in rural areas (Baker & Lim, 2012). The only individual recorded in this study has a standard length of 7.6 cm.

Family Osphronemidae

Betta pugnax (Cantor, 1849)
(Fig. 33)

Macropodus pugnax Cantor, 1849: 1066, pl. 2 figs. 1–3.
Betta pugnax Alfred, 1966: 49; Lim & Ng, 1990: 94; Ng & Lim, 1996: 114; 1997: 247; Baker & Lim, 2012: 46; Kottelat, 2013: 452.

Fig. 33. *Betta pugnax* from Nee Soon Swamp Forest, 3.7 cm SL.

Common name. Malayan forest betta.

Status in Singapore. Native, common, restricted to a few areas.

Status in NSSF. Common, widespread, present in all 12 sites.

Distribution. Malay Peninsula and Sumatra. Singapore: Bukit Timah Nature Reserve and Central Catchment Nature Reserve.

Description. *Betta pugnax* is an abundant and widespread species in Nee Soon Swamp Forest. Its body coloration varies from brown with greenish-blue spots to brown with blackish stripes (Baker & Lim, 2012). This species frequents middle to lower water levels in shaded forest streams and can be easily captured by both netting and trapping. Males typically oralbrood the eggs and when agitated will expel live juveniles from their mouths. It is the third most abundant fish in Nee Soon Swamp Forest (Fig. 44). Individuals recorded in this study have a mean standard length of 3.6 cm ± 1.3 cm (n = 435).

Luciocephalus pulcher (Gray, 1830)
(Fig. 34)

Diplopterus pulcher Gray, 1830: vol. 1, pl. 87 fig. 1.
Luciocephalus pulcher Alfred, 1966: 54; Lim & Ng, 1990: 102; Ng & Lim, 1996: 114; 1997: 247; Lim et al., 2008: 151; Baker & Lim, 2012: 45; Kottelat, 2013: 453.

Common name. Malayan pikehead.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Fig. 34. *Luciocephalus pulcher* from Nee Soon Swamp Forest, 2.8 cm SL.

Status in NSSF. Uncommon, present in sites 3–9.

Distribution. Malay Peninsula, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest and Sime Road Forest.

Description. *Luciocephalus pulcher* has a distinctively elongated and pointed snout. The dorsal surface is brown and a thin black stripe is visible along the lower side of its body. It has a highly protractile mouth that is adapted for catching or swallowing other fish (Lim & Ng, 1990; Baker & Lim, 2012). This fish is usually seen singly near the surface of shallow and slow flowing streams. Like the soon hock, it is an ambush predator. Individuals recorded in this study have a mean standard length of 5.0 ± 2.8 cm (n = 26).

Trichopodus trichopterus (Pallas, 1770)

(Fig. 35)

Labrus trichopterus Pallas, 1770: 45.
Trichogaster trichopterus Alfred, 1966: 52; Lim & Ng, 1990: 98; Ng & Lim, 1996: 114; 1997: 247.
Trichopodus trichopterus Baker & Lim, 2012: 47; Low & Lim, 2012: 84, figs 1–4; Kottelat, 2013: 457.

Common name. Three-spot gourami.

Status in Singapore. Native, common, widespread.

Status in NSSF. Rare, restricted to sites 1 and 2.

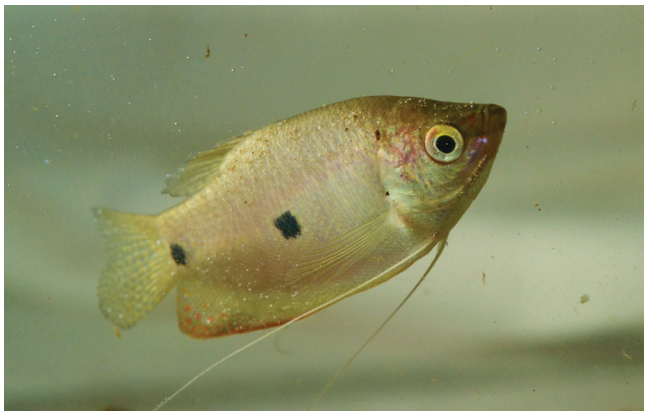

Fig. 35. *Trichopodus trichopterus* from Nee Soon Swamp Forest, 5.5 cm SL.

Distribution. Indochina, Malay Peninsula, Java, Sumatra and Borneo. Singapore: Jurong Road, Sembawang Hot Spring, West Coast Road, Sungei Kranji, Mandai Road, Upper Seletar Reservoir and Nee Soon Swamp Forest (Low & Lim, 2012).

Description. *Trichopodus trichopterus* has two prominent black spots on its laterally compressed body, one in the middle of the body and the other at the base of the caudal fin. Its anal fin is dotted with orange spots. This species is usually found hiding in dense vegetation and has a preference for exposed streams. Individuals recorded in this study have a mean standard length of 5.6 ± 2.0 cm (n = 8).

Trichopsis vittata (Cuvier, in Cuvier & Valenciennes, 1831)

(Fig. 36)

Osphromenus vittatus Cuvier, in Cuvier & Valenciennes, 1831: 387.
Trichopsis vittata Alfred, 1966: 53, pl. 8, fig. 3; Lim & Ng, 1990: 95; Ng & Lim, 1996: 113; 1997: 247; Baker & Lim, 2012: 45; Kottelat, 2013: 458.

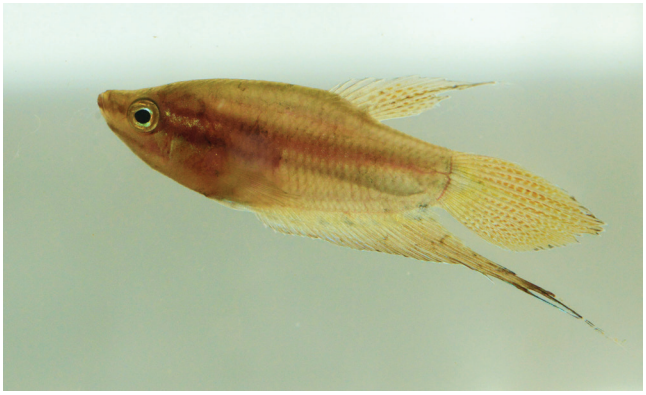

Fig. 36. *Trichopsis vittata* from Nee Soon Swamp Forest, 3.3 cm SL.

Common name. Croaking gourami.

Status in Singapore. Native, uncommon, widespread.

Status in NSSF. Uncommon, restricted to site 1.

Distribution. Indochina, Malay Peninsula, Java, Sumatra and Borneo. Singapore: Nee Soon Swamp Forest, Sembawang Hot Spring, MacRitchie Reservoir, Upper Seletar Reservoir, Botanic Gardens, Kranji Reservoir, Jurong Road and Mandai.

Description. *Trichopsis vittata* may be easily misidentified as *Betta pugnax*, but it has a less robust head with narrow dorsal head width, while *Betta pugnax* has a more robust head and broader dorsal head width (Fig. 37). The croaking gourami is a common species occurring at site 1 and usually resides in dense aquatic vegetation near the banks. Individuals recorded in this study have a mean standard length of 2.3 ± 1.1 cm (n = 9).

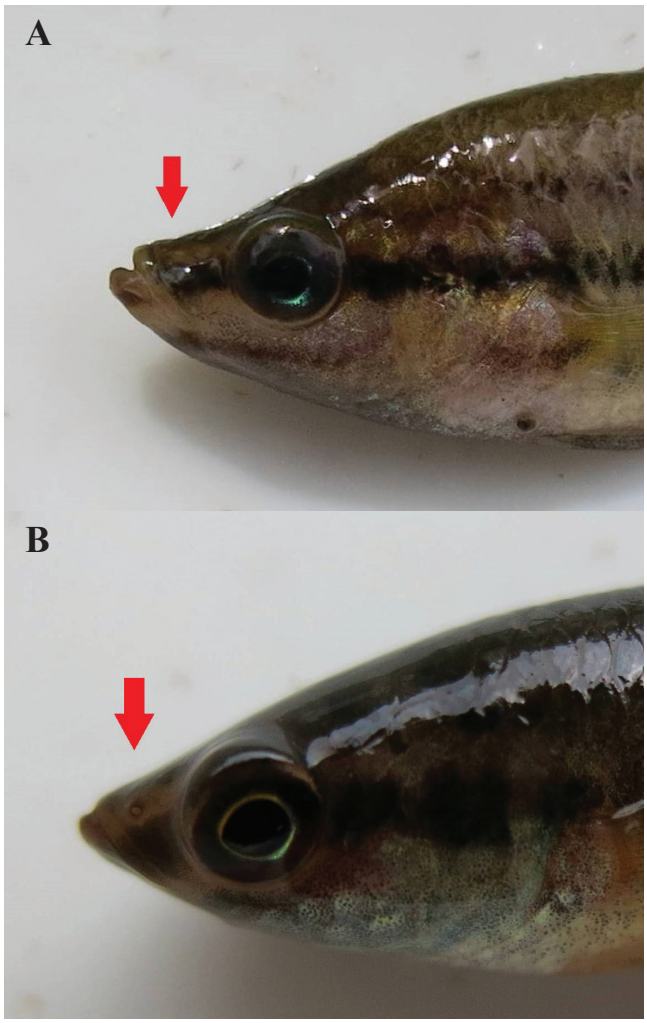

Fig. 37. *Trichopsis vittata*: A, a less robust head with narrow dorsal head width; B, *Betta pugnax* has a more robust head with broad dorsal head width.

Family Channidae

Channa gachua (Hamilton, 1822)
(Fig. 38)

Ophiocephalus gachua Hamilton, 1822: 68, 367, pl. 21 fig. 21.
Channa orientalis Alfred, 1966: 56.
Channa gachua Ng & Lim, 1989: 172; 1990:Lim & Ng, 1990: 106; Lee & Ng, 1994:63; Ng & Lim, 1996: 114; 1997: 247; Lim et al., 2008: 152; Baker & Lim, 2012: 48; Kottelat, 2013: 459.

Common name. Dwarf snakehead.

Fig. 38. *Channa gachua* from Nee Soon Swamp Forest, 10.7 cm SL.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Rare, restricted to site 3.

Distribution. East and Southeast Asia. Singapore: Nee Soon Swamp Forest and Chestnut Drive forest.

Description. *Channa gachua* can be easily recognised by its green to bluish dorsal, caudal and anal fins with bright orange margins. Black bars are present on the pectoral fins (Baker & Lim, 2012). It is the smallest of the four *Channa* species in Nee Soon Swamp Forest and was only recorded from the shaded and shallow small streams in site 3. This species was reported as extinct in Singapore in the past (Alfred, 1966) but rediscovered in 1989 by Ng & Lim. Individuals recorded in this study have a mean standard length of 10.1 ± 0.4 cm (n = 3).

Channa lucius (Cuvier, in Cuvier & Valenciennes, 1831)
(Fig. 39)

Ophicephalus lucius Cuvier, in Cuvier & Valenciennes, 1831: 416.
Channa lucius Alfred, 1966: 55; Lim & Ng, 1990: 110; Lee & Ng, 1994: 63; Ng & Lim, 1996: 114; 1997: 247; Baker & Lim, 2012: 48; Kottelat, 2013: 460.

Fig. 39. *Channa lucius*: A, Adult from Nee Soon Swamp Forest, 9.0 cm SL; B, Juvenile *Channa lucius* with two lateral black stripes, 4.9 cm SL.

Common name. Forest snakehead.

Status in Singapore. Native, uncommon, restricted to a few areas.

Status in NSSF. Uncommon, present in sites 1, 2, 4, 6, 7, 8 and 10.

Distribution. Indochina, Malay Peninsula, Java, Sumatra and Borneo. Singapore: Upper Seletar Reservoir, MacRitchie Reservoir, Lower Peirce Reservoir, Nee Soon Swamp Forest and Sime Road forest.

Description. *Channa lucius* has a distinct black stripe behind the eye and a series of black blotches along the sides of its body, with distinct white spots on the pectoral fins in adults. They usually occur singly or in pairs in forested streams (Baker & Lim, 2012). It escapes readily upon slight disturbance and was captured almost entirely by trapping. The juveniles of *Channa lucius* have two black stripes extending from the head to the base of the caudal fin. The Forest Snakehead is the most common *Channa* species in Nee Soon Swamp Forest. Individuals recorded in this study have a mean standard length of 10.1 ± 10.9 cm (n = 17).

***Channa melasoma* (Bleeker, 1851)**
(Fig. 40)

Ophicephalus melasoma Bleeker, 1851c: 424.
Channa melasoma Ng & Lim, 1990a: 21–24; Lee & Ng, 1994:63; Ng & Lim, 1996: 114; 1997: 247; Lim et al., 2008: 152; Baker & Lim, 2012: 49; Kottelat, 2013: 461; Baker, 2014: 273.

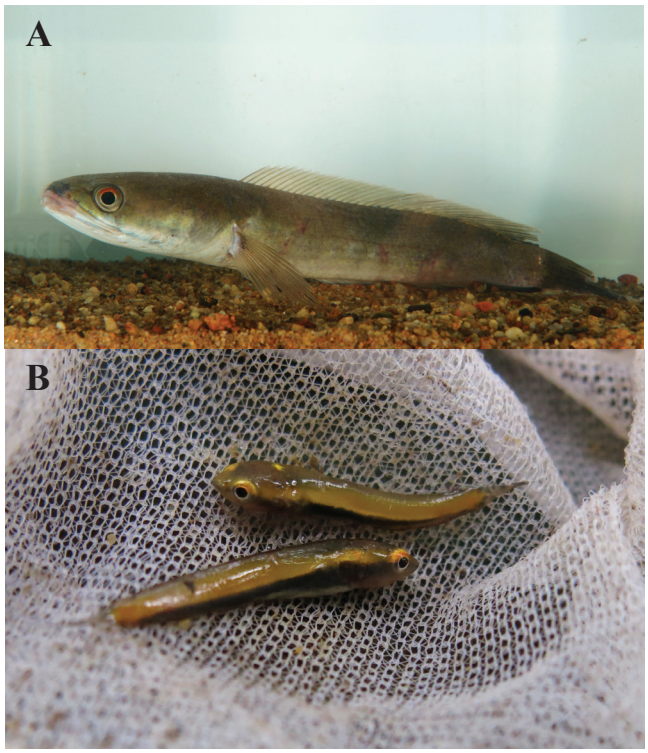

Fig. 40. *Channa melasoma*: A, Adult from Nee Soon Swamp Forest, 16.0 cm SL; B, Juvenile with two lateral black stripes, 1.6 cm SL.

Common name. Black snakehead.

Status in Singapore. Native, critically endangered, restricted to a few areas.

Status in NSSF. Uncommon, present in sites 3, 7, 8, 11 and 12.

Distribution. Malay Peninsula, Sumatra (Riau islands) and Borneo. Singapore: Nee Soon Swamp Forest, Lower Peirce forest and Bukit Timah Nature Reserve (Baker, 2014).

Description. *Channa melasoma* is characterised by its slender body that is grey to almost black. The anal, dorsal and caudal fins often have distinctive white margins (Baker & Lim, 2012). This elusive species inhabits shaded forest streams and is usually found hiding under leaf litter or in between submerged roots. Juveniles of this species can be recognised by a white spot on the dorsal part of the head (Ng & Lim, 1990). Individuals recorded in this study have a mean standard length of 8.8 ± 10.6 cm (n = 4).

***Channa striata* (Bloch, 1793)**
(Fig. 41)

Ophicephalus striatus Bloch, 1793: 141, pl. 359.
Channa striata Alfred, 1966: 56–57; Lim & Ng, 1990: 105; Lee & Ng, 1994: 64; Ng & Lim, 1996: 114; 1997: 247; Baker & Lim, 2012: 47; Kottelat, 2013: 462.

Fig. 41. *Channa striata* from MacRitchie forest. 5.5 cm SL.

Common name. Common snakehead.

Status in Singapore. Native, common, widespread.

Status in NSSF. Rare, restricted to sites 3 and 11.

Distribution. India, Indochina, Malay Peninsula, Sumatra, Borneo and Java. Singapore: Kranji Reservoir, Upper Selelar Reservoir, Botanic Gardens, Nee Soon Swamp Forest, Lower Peirce Reservoir, Mandai and many urban water bodies.

Description. *Channa striata* is characterised by a slender body which is greyish brown above with irregular blackish bars and white below. This species is found in forest streams, rural areas, reservoirs and concretised waterways (Baker & Lim, 2012). Juveniles of this species have a broad orange stripe laterally across the body and a black spot on the posterior part of their dorsal fin (Ng & Lim, 1990). This is the least common *Channa* species in Nee Soon Swamp Forest. Individuals recorded in this study have a mean standard length of 20.2 ± 4.2 cm (n = 2)

RESULTS

Species account. A total of 36 freshwater fish species are recorded in this study, 30 are native to Singapore and six are introduced from Southeast Asia, China and Southern Mexico. National conservation status of each species is based on Lim et al. (2008) and Baker & Lim (2012).

Distribution. Quantitative surveys were carried out at the main sampling sites 1–12 and qualitative surveys were

Table 2. Distribution and Mean abundance of freshwater fishes at quantitative sites 1–12. (Abbreviations: +++: Abundant (>5.00), ++: Common (1.01–5.00), +: Rare (0.12–1.00), –: Not Found at site, * denotes introduced species)

Species	Sites											
	1	2	3	4	5	6	7	8	9	10	11	12
Order CYPRINIFORMES												
Family Cyprinidae												
Barbodes banksi	++	++	++	+	++	+	++	+	+	+	+	–
Barbodes lateristriga	–	–	++	+	–	+	–	–	–	–	+	–
Boraras maculatus	–	+++	–	–	–	–	–	–	–	–	–	–
Desmopuntius hexazona	–	–	+	++	+	+	++	–	–	–	–	–
*Osteochilus vittatus**	++	–	–	–	–	–	–	–	–	–	–	–
*Puntigrus tetrazona**	+	–	–	–	–	–	–	–	–	–	–	–
*Rasbora borapetensis**	+	–	–	–	–	–	–	–	–	–	–	–
Rasbora einthovenii	+	+++	+	++	++	+	++	++	+	++	–	++
Rasbora elegans	+++	+++	+++	+++	++	++	++	++	++	++	–	+
Trigonostigma heteromorpha	–	+	+++	+++	+++	+++	+++	++	++	+++	++	++
Family Cobitidae												
Pangio muraeniformis	+	+	+++	++	+++	++	+	–	++	++	++	+
Family Nemacheilidae												
Nemacheilus selangoricus	–	–	++	++	+++	+++	+	++	+	+	++	++
Order SILURIFORMES												
Family Akysidae												
Parakysis longirostris	–	+	+	+	+	+	+	–	+	+	+	–
Family Siluridae												
Silurichthys hasseltii	–	–	+	–	–	+	+	+	–	–	–	–
Family Clariidae												
Clarias leiacanthus	+	+	+	+	+	+	+	+	+	+	+	+
Clarias nieuhofii	–	–	–	–	–	–	+	+	–	–	–	–
Family Bagridae												
Pseudomystus leiacanthus	–	–	+	–	+	–	–	–	–	–	–	–
Order BELONIFORMES												
Family Zenarchopteridae												
Dermogenys collettei	+++	–	–	–	–	–	–	–	–	–	–	–
Hemirhamphodon pogonognathus	++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Order CYPRINODONTIFORMES												
Family Aplocheilidae												
Aplocheilus panchax	–	+	–	–	–	–	–	–	–	–	–	–
Family Poeciliidae												
*Poecilia sphenops**	+	–	–	–	–	–	–	–	–	–	–	–
ORDER SYNBRANCHIFORMES												
Family Synbranchidae												
Monopterus javanensis	+	–	–	–	–	–	–	–	–	–	–	–
Family Mastacembelidae												
Macrognathus maculatus	+	+	+	+	+	+	+	+	+	+	+	+
Order PERCIFORMES												
Family Ambassidae												
*Parambassis siamensis**	+	–	–	–	–	–	–	–	–	–	–	–
Family Eleotridae												
Oxyeleotris marmorata	++	++	+	–	–	–	–	–	–	–	–	–

Species	Sites											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Family Gobinellidae												
Pseudogobiopsis oligactis	++	+	–	–	–	–	–	–	–	–	–	–
*Rhinogobius giurinus**	+++	+	–	–	–	–	–	–	–	+	–	–
Family Anabantidae												
Anabas testudineus	+	–	–	–	–	–	–	–	–	–	–	–
Family Osphronemidae												
Betta pugnax	++	+++	+++	++	+++	++	+++	+++	++	+	++	++
Luciocephalus pulcher	–	–	++	+	+	+	+	+	+	–	–	–
Trichopodus trichopterus	+	+	–	–	–	–	–	–	–	–	–	–
Trichopsis vittata	++	–	–	–	–	–	–	–	–	–	–	–
Family Channidae												
Channa gachua	–	–	+	–	–	–	–	–	–	–	–	–
Channa lucius	+	+	–	+	–	+	+	+	–	+	–	–
Channa melasoma	–	–	+	–	–	–	+	+	–	–	+	+
Channa striata	–	–	+	–	–	–	–	–	–	–	+	–

Table 3. Distribution and Total abundance of freshwater fishes at qualitative sites 13–20. (Abbreviations: +: Present, –: Absent)

Species	Sites							
	13	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Family Cyprinidae								
Barbodes banksi	–	–	+	–	–	–	–	+
Barbodes lateristriga	–	–	+	–	–	–	–	–
Boraras maculatus	–	–	–	–	+	+	–	–
Rasbora einthovenii	+	+	–	+	–	+	–	+
Rasbora elegans	+	–	+	–	+	+	–	–
Trigonostigma heteromorpha	–	–	+	–	+	+	–	–
Family Cobitidae								
Pangio muraeniformis	–	–	–	–	+	+	–	–
Family Nemacheilidae								
Nemacheilus selangoricus	–	–	–	–	+	–	–	–
Family Clariidae								
Clarias nieuhofii	–	+	–	–	–	–	–	–
Family Zenarchopteridae								
Hemirhamphodon pogonognathus	–	–	+	–	–	+	–	+
Family Mastacembelidae								
Macrognathus maculatus	–	–	–	–	–	+	–	–
Family Osphronemidae								
Betta pugnax	–	+	–	+	–	+	–	-

conducted at sites 13–20. Table 2 and Table 3 list the species of freshwater fishes found in each of these sites.

Ten native fish species, namely *Rasbora einthovenii*, *R. elegans*, *Barbodes banksi*, *Trigonostigma heteromorpha*, *Pangio muraeniformis*, *Nemacheilus selangoricus*, *Clarias leiacanthus*, *Macrognathus maculatus*, *Hemirhamphodon pogonognathus* and *Betta pugnax* were identified as having a wide distribution, being found in at least 10 of the 12 main sampling sites. However, only the last two species were abundant throughout all 12 sites.

In contrast, seven native fish species were recorded from a single locality with five species occurring less than nine times throughout the survey. Among these, most species were restricted to sites 1 or 2 and *Channa gachua* was

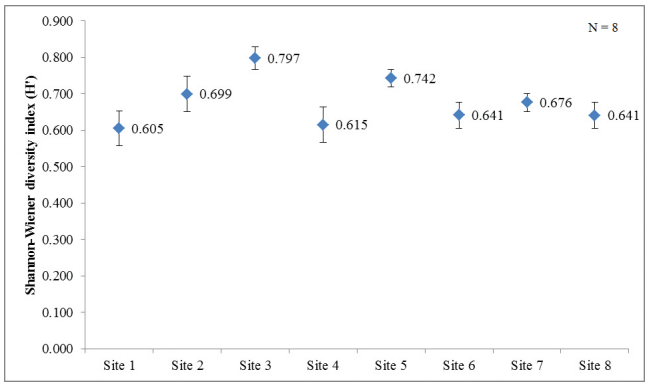

Fig. 42. Average Shannon-Weiner diversity index (H') for native freshwater fish at all survey sites. (Error Bars: +/- 1 S.E, N=8.)

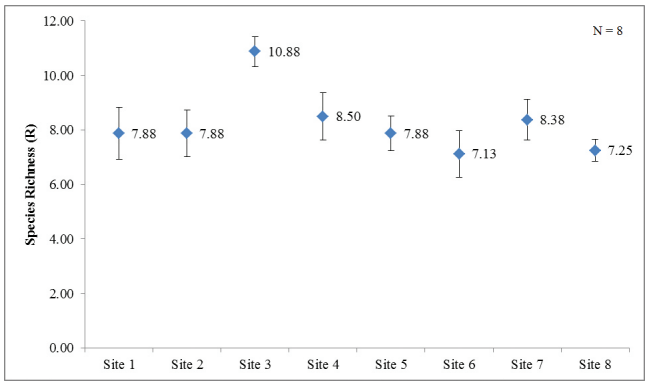

Fig. 43. Average Species Richness (R) for native freshwater fish at all survey sites. (Error Bars: +/- 1 S.E, N=8.)

restricted to site 3 (Table 2). Only *Boraras maculatus* and *Dermogenys collettei* were recorded more than 50 times throughout the survey. With the exception of *Rhinogobius giurinus*, all the other five introduced species, *Osteochilus vittatus*, *Rasbora borapetensis*, *Puntigrus tetrazona*, *Poecilia sphenops* and *Parambassis siamensis* were found only in site 1 at the outskirts of NSSF.

In quantitative sampling sites 13–20, *Rasbora einthovenii* was the only species found to be widespread (at five out of eight sites. Most sites had less than five species with only site 18 exceeding eight species (Table 3).

Species diversity and richness. Based on the Shannon-Weiner index (H') calculated on the eight main sampling sites, site 3 in the core of NSSF with a large open pond had the highest species diversity (H'= 0.797) of native fish with a maximum of 14 species, while site 4 had the lowest species diversity (H'=0.615) of native fish with a minimum of four species (Fig. 42).

The Species Richness (R) indicates the average number of fish species present at each of the survey sites. It was evident from the analysis that site 3 has the highest native species richness (R=10.88) and site 6 has the lowest native species richness (R=7.13) (Fig. 43).

Abundance. The four most abundant native species found in Nee Soon Swamp Forest were *Trigonostigma heteromorpha* (17.17), *Hemirhamphodon pogonognathus* (11.89), *Betta pugnax* (6.80) and *Rasbora elegans* (6.07). All four species had a mean abundance of more than 6 per series of sampling per site (Fig. 44). Introduced species were very low in mean abundance with less than 1 individual per cycle of sampling per site.

ANOVA results indicated that the mean abundance of 22 of the 36 total species of freshwater fish were significantly different between the eight sites surveyed (Table 4). However, 12 native species: *Anabas testudineus*, *Aplocheilus panchax*, *Barbodes banksi*, *Channa gachua*, *Channa lucius*, *Channa melasoma*, *Channa striata*, *Clarias leiacanthus*, *Clarias nieuhofii*, *Macrognathus maculatus*, *Pseudomystus leiacanthus*, *Silurichthys hasseltii*, and one introduced species *Poecilia sphenops* did not differ in abundance between sites.

The three most abundant native species, *Trigonostigma heteromorpha*, *Hemirhamphodon pogonognathus*, and *Betta pugnax* had lower mean abundance at site 1 compared to the rest (Figs. 46–48).

When the abundance of freshwater fish was analysed across eight sampling cycles, significant differences were observed in the mean abundance of two native species, *Hemirhamphodon pogonognathus* and *Betta pugnax* (Table 5). The mean abundance of *Hemirhamphodon pogonognathus* was significantly lower in series 5 and 6 compared to the rest of the series (Fig. 51). Similarly, the mean abundance of *Betta pugnax* was significantly lower in series 1, 5, and 6 (Fig. 52). The same trend was observed in the mean abundance of *Rasbora elegans* and *Trigonostigma heteromorpha* in series 6 (Figs. 49, 50). Series 5 and 6 correspond to the Northeast monsoon in September to November with abundant rainfall and very wet conditions in the swamp forest.

DISCUSSION

Species diversity and abundance of freshwater fish. Thirty species of native freshwater fish have been documented in the current biodiversity assessment of Nee Soon Swamp Forest. This rich species diversity may possibly be due to the different habitat structures and microhabitats that constitute the respective survey sites (Gorman & Karr, 1978). Some species thrive better in fast flowing streams while others prefer slow moving and still waters. Fishes also frequent different water levels, with some preferring upper to low levels while others are strictly surface or bottom dwellers. Fishes found in swamp forests are usually adapted to acidic water conditions. Thus, the fishes to be found at survey sites will differ depending on the availability of suitable niches. Analysis of the species diversity at individual sites using the Shannon-Weiner index showed that site 3 in the middle of Nee Soon Swamp Forest supported the highest diversity and richness of native freshwater fish. This site has a deep open pond with slow water flow and is directly connected to the forest boundaries at both ends by shallow streams. The sandy substrate, uneven stream bed flanked with large patches of aquatic vegetation and leaf litter contained a variety of microhabitats stratified for different species of fish, which could account for the high species diversity. Despite being less than 100 metres apart, site 4 was found to have the lowest

Table 4. One-way analysis of variance on the mean abundance of freshwater fishes between eight survey sites in Nee Soon Swamp Forest (significant values in bold, * denotes introduced species).

Species	df	F	p
Family Cyprinidae			
Barbodes banksi	7,56	1.321	.257
Barbodes lateristriga	7,56	5.755	**.000**
Boraras maculatus	7,56	2.998	**.010**
Desmopuntius hexazona	7,56	2.619	**.021**
*Osteochilus vittatus**	7,56	9.615	**.000**
*Rasbora borapetensis**	7,56	2.333	**.037**
Rasbora einthovenii	7,56	5.698	**.000**
Rasbora elegans	7,56	10.003	**.000**
Trigonostigma heteromorpha	7,56	4.740	**.000**
Family Cobitidae			
Pangio muraeniformis	7,56	8.533	**.000**
Family Nemacheilidae			
Nemacheilus selangoricus	7,57	6.941	**.000**
Family Akysidae			
Parakysis longirostris	7,56	2.476	**.027**
Family Siluridae			
Silurichthys hasseltii	7,56	.633	.727
Family Clariidae			
Clarias leiacanthus	7,56	1.695	.129
Clarias nieuhofii	7,56	.857	.546
Family Bagridae			
Pseudomystus leiacanthus	7,56	.857	.546
Family Zenarchopteridae			
Dermogenys collettei	7,56	13.299	**.000**
Hemirhamphodon pogonognathus	7,56	2.567	**.023**
Family Aplocheilidae			
Aplocheilus panchax	7,56	1.000	.441
Family Poeciliidae			
*Poecilia sphenops**	7,56	1.000	.441
Family Synbranchidae			
Monopterus javanensis	7,56	2.333	**.037**
Family Mastacembelidae			
Macrognathus maculatus	7,56	.842	.557
Family Ambassidae			
*Parambassis siamensis**	7,56	2.333	**.037**
Family Eleotridae			
Oxyeleotris marmorata	7,56	7.891	**.000**
Family Gobinellidae			
Pseudogobiopsis oligactis	7,56	6.277	**.000**
*Rhinogobius giurinus**	7,56	4.308	**.001**
Family Anabantidae			
Anabas testudineus	7,56	1.000	.441
Family Osphronemidae			
Betta pugnax	7,56	5.028	**.000**
Luciocephalus pulcher	7,56	2.695	**.018**
Trichopodus trichopterus	7,56	5.419	**.000**
Trichopsis vittata	7,56	2.296	**.040**
Family Channidae			
Channa gachua	7,56	2.032	.067
Channa lucius	7,56	1.274	.280
Channa melasoma	7,56	.762	.621
Channa striata	7,56	1.000	.441

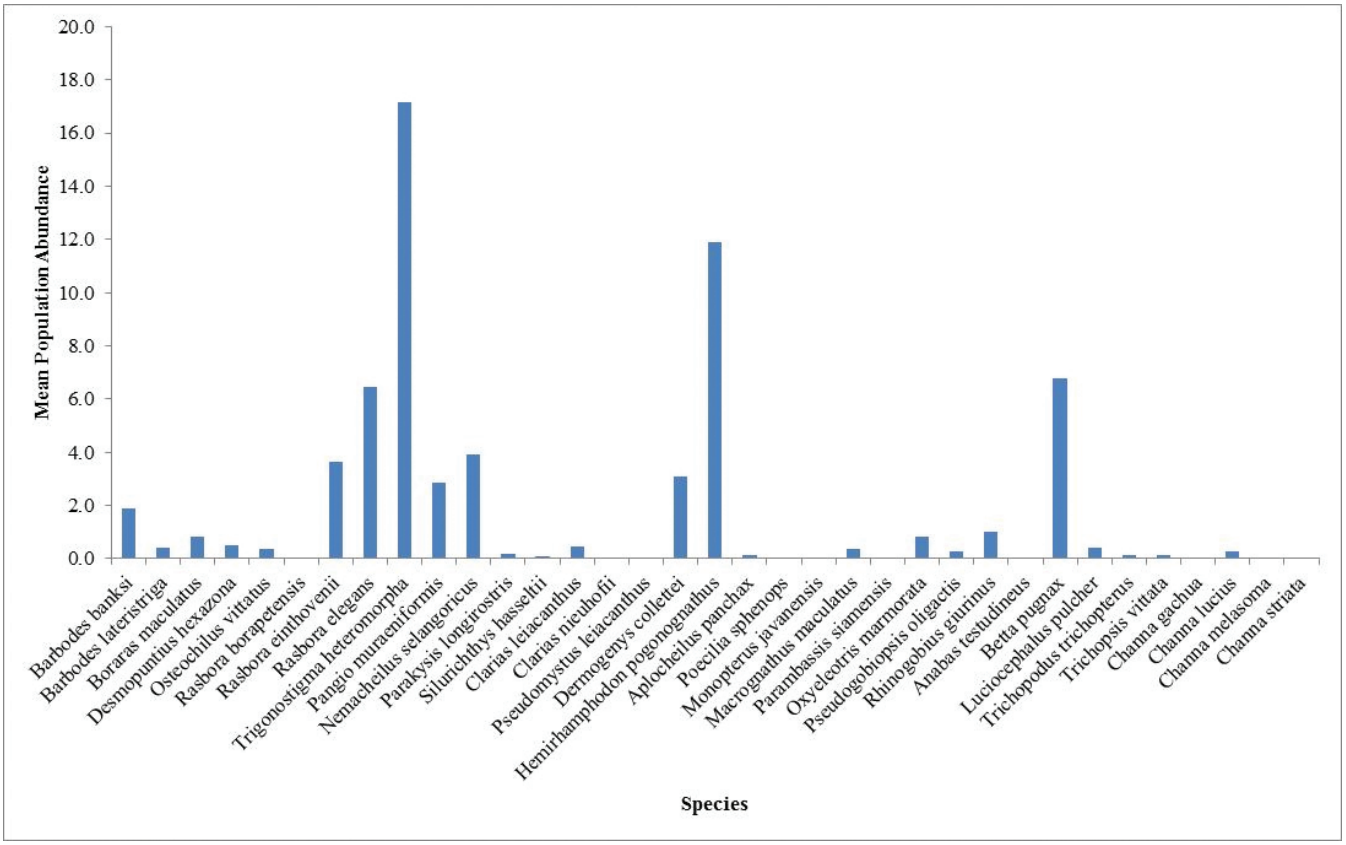

Fig. 44. Mean Population Abundance of freshwater fishes present in all survey sites.

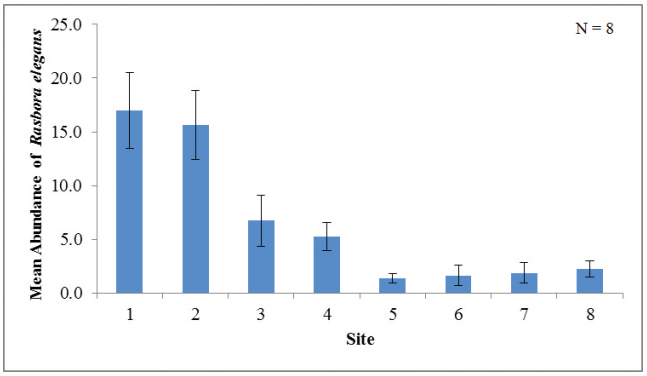

Fig. 45. Mean Abundance of *Rasbora elegans* over 8 survey sites. Error bars: +/- 1 S.E.

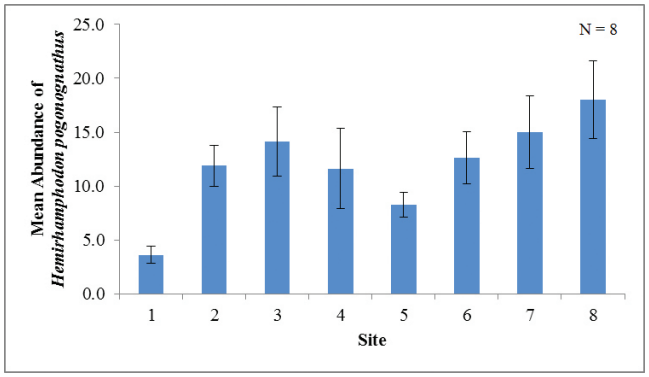

Fig. 47. Mean Abundance of *Hemirhamphodon pogonognathus* over 8 survey sites. Error bars: +/- 1 S.E

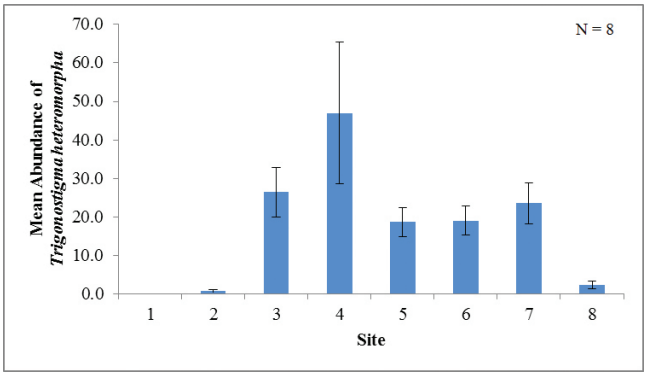

Fig. 46. Mean Abundance of *Trigonostigma heteromorpha* over 8 survey sites. Error bars: +/- 1 S.E.

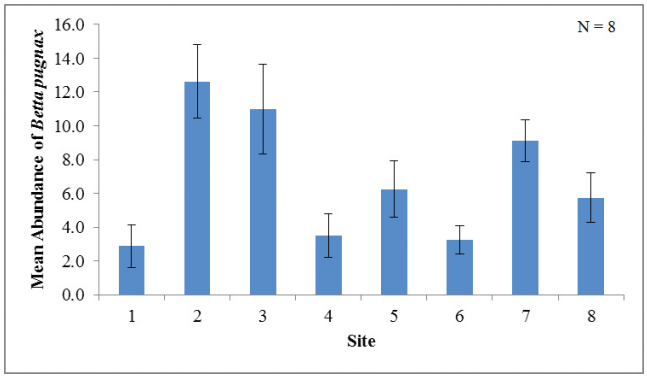

Fig. 48. Mean Abundance of *Betta pugnax* over 8 survey sites. Error bars: +/- 1 S.E.

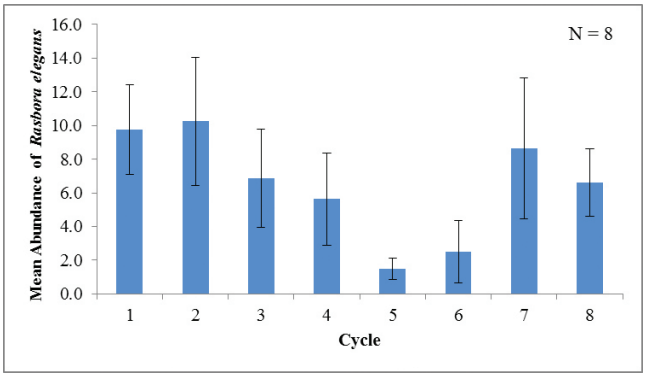

Fig. 49. Mean Abundance of *Rasbora elegans* over 8 time cycles. Error bars: +/- 1 S.E.

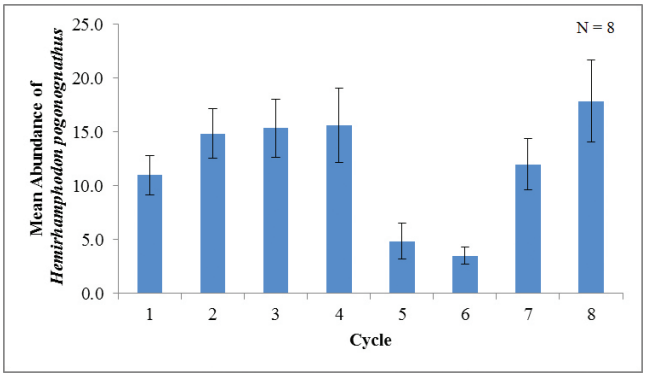

Fig. 51. Mean Abundance of *Hemirhamphodon pogonognathus* over 8 time cycles. Error bars: +/- 1 S.E.

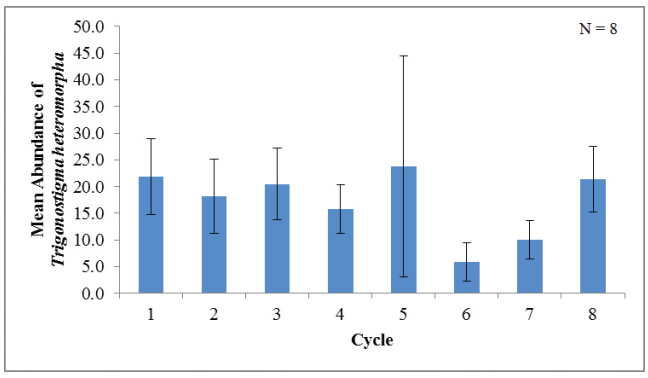

Fig. 50. Mean Abundance of *Trigonostigma heteromorpha* over 8 time cycles. Error bars: +/- 1 S.E.

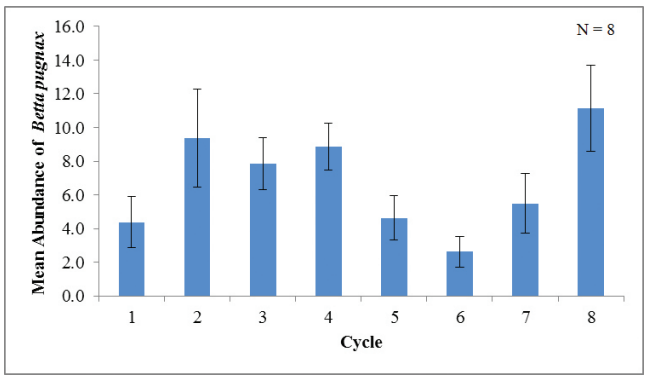

Fig. 52. Mean Abundance of *Betta pugnax* over 8 time cycles. Error bars: +/- 1 S.E.

species diversity of native freshwater fish. This might be due to the uniformity of the stream channel, water depth and less microhabitats at this site, which resulted in dominance of particular species like *Trigonostigma heteromorpha* and *Hemirhamphodon pogonognathus* and absence of other species that might prefer slightly different conditions. At the outskirts of Nee Soon Swamp Forest, site 1 supported the highest species diversity of introduced fish, which were also restricted to this area with the exception of one species *Rhinogobius giurinus*. The high light intensity and largely exposed stream conditions in site 1 encouraged growth of dense clumps of *Hydrilla verticillata*, which provided food by harbouring small invertebrates and shelter for the freshwater fish. This coupled with the periodic release of water from the Upper Seletar Reservoir might have contributed to the high species diversity of introduced fish in site 1 (Ng & Tan, 2010).

The four most abundant native species found in Nee Soon Swamp Forest were *Trigonostigma heteromorpha*, *Hemirhamphodon pogonognathus*, *Rasbora elegans* and *Betta pugnax*. These species were also generally widely distributed and consistently collected in every sampling cycle. The acidic, cool and closed canopied streams in Nee Soon Swamp Forest provided optimum conditions for the survival and propagation of these typical swamp forest fishes. The undulating stream bed and water depth also created a variety of suitable habitats, such as shallow and low oxygenated streams for *Betta pugnax*, and deeper pools with fast-flowing water for the cyprinids. The lower abundance of *Trigonostigma heteromorpha*, *Hemirhamphodon pogonognathus*, and *Betta pugnax* at site 1 might be due to competition from introduced species which were restricted to this site. It was also observed that the mean abundance of these species were much lower during September to November. This could be due to the onset of the Northeast monsoon and associated floods, which flushed some of the species downstream prior to and during sampling events. The elevated water level also made it difficult to manoeuvre hand nets in the streams, reducing the overall catch.

Physical habitat variables and water parameters like dissolved oxygen, water depth, pH have been shown to play a key role in species diversity (Lakra et al., 2010). The riparian and aquatic vegetation not only influence the light and shade in the streams, but also help to maintain habitat structure, water clarity and the aquatic food web (Pusey & Arthington, 2003). It has also been demonstrated that species abundance tends to increase with the stability of substrates and presence of organic particulate matter (Giller & Malmqvist, 1998). It was evident that site 1 with the highest mean pH (5.97) and temperature (26.3°C) had the lowest abundance of native species as these fishes prefer cool forested streams with relatively high acidity. On the other hand, the deep pond in site 3 allowed for accumulation of organic leaf litter and deposition of substrates, which might have contributed to the high species diversity of native fish. The integration of biotic and abiotic factors directly and indirectly influences the distribution, diversity and abundance of freshwater fish in Nee Soon Swamp Forest.

Table 5. One-way analysis of variance on the mean abundance of freshwater fishes between eight survey series in Nee Soon Swamp Forest (significant values in bold, * denotes introduced species).

Species	df	F	p
Family Cyprinidae			
Barbodes banksi	7,56	1.488	.190
Barbodes lateristriga	7,56	.547	.795
Boraras maculatus	7,56	.800	.591
Desmopuntius hexazona	7,56	2.077	.061
*Osteochilus vittatus**	7,56	.481	.844
*Rasbora borapetensis**	7,56	.857	.546
Rasbora einthovenii	7,56	.516	.818
Rasbora elegans	7,56	1.288	.273
Trigonostigma heteromorpha	7,56	.482	.844
Family Cobitidae			
Pangio muraeniformis	7,56	.819	.576
Family Nemacheilidae			
Nemacheilus selangoricus	7,56	.799	.592
Family Akysidae			
Parakysis longirostris	7,56	.627	.731
Family Siluridae			
Silurichthys hasseltii	7,56	.633	.727
Family Clariidae			
Clarias leiacanthus	7,56	.290	.955
Clarias nieuhofii	7,56	.857	.546
Family Bagridae			
Pseudomystus leiacanthus	7,56	.857	.546
Family Zenarchopteridae			
Dermogenys collettei	7,56	.394	.902
Hemirhamphodon pogonognathus	7,56	4.237	**.001**
Family Aplocheilidae			
Aplocheilus panchax	7,56	1.000	.441
Family Poeciliidae			
*Poecilia sphenops**	7,56	1.000	.441
Family Synbranchidae			
Monopterus javanensis	7,56	.857	.546
Family Mastacembelidae			
Macrognathus maculatus	7,56	1.739	.119
Family Ambassidae			
*Parambassis siamensis**	7,56	.857	.546
Family Eleotridae			
Oxyeleotris marmorata	7,56	.525	.812
Family Gobinellidae			
Pseudogobiopsis oligactis	7,56	.764	.619
*Rhinogobius giurinus**	7,56	.815	.579
Family Anabantidae			
Anabas testudineus	7,56	1.000	.441
Family Osphronemidae			
Betta pugnax	7,56	2.528	**.025**
Luciocephalus pulcher	7,56	.527	.810
Trichopodus trichopterus	7,56	.851	.550
Trichopsis vittata	7,56	.861	.543
Family Channidae			
Channa gachua	7,56	.886	.524
Channa lucius	7,56	.869	.536
Channa melasoma	7,56	.762	.621
Channa striata	7,56	1.000	.441

New record of native species found in Nee Soon Swamp Forest. In the previous study by Ng & Lim (1997), 25 species of native freshwater fish were found in Nee Soon Swamp Forest, and all these species were recorded in the current biodiversity survey conducted during February to December 2013 and January to March 2014. The current survey also recorded an additional native species new to NSSF: *Barbodes lateristriga*. This forest species was previously recorded only from the Sime Road Forest, Lower Peirce Forest, Bukit Timah Nature Reserve and MacRitchie Reservoir (Alfred, 1966; Ng & Lim, 1997). Within NSSF, *Barbodes lateristriga* was observed mostly in the middle swamps with moderate canopy coverage and deep, open stretches of water converging to large ponds. The largest population occurred in the main pond at site 3. Individuals captured at this site were also significantly larger in body size than those obtained elsewhere in NSSF, which might be associated with the nutrient-rich water and stable physical habitat discussed in the earlier section.

Presence of introduced species in Nee Soon Swamp Forest. Introduced fish can have severe impacts on the native fish ecology, causing decline of native fish population and possibly extinction (Barel et al. 1985; Herder et al., 2012). Through the course of this survey, six species of introduced fish have been recorded and all are common and widespread throughout Singapore. These species include *Osteochilus vittatus*, *Parambassis siamensis*, *Poecilia sphenops*, *Puntigrus tetrazona, Rasbora borapetensis* and *Rhinogobius giurinus*, of which all but *Osteochilus* and *Puntigrus* species were previously not recorded from Nee Soon. Five of these species were restricted to site 1, and *Rhinogobius giurinus* was also found in site 2 and site 10. Larson & Lim (2005) documented that *Rhinogobius giurinus* has been outcompeting the local species of freshwater goby, *Pseudogobiopsis oligactis* at locations where the two populations overlap, a result corroborated by this survey, as both species of gobies have been recorded at sites 1 and 2, but the mean abundance of *Rhinogobius giurinus* was much higher than *Pseudogobiopsis oligactis* at both sites with a ratio of 3:1.

The less acidic water in sites 1 and 2 could have encouraged propagation of introduced species over natives better adapted to the swamp forest stream habitat. As the lower reach of site 1 is connected to the spillway of Upper Seletar Reservoir, this inevitably subjects the site to occasional flooding when excess water is released from Upper Seletar Reservoir. Such events might indirectly introduce foreign fishes that reside in the water bodies of the reservoir (Ng & Tan, 2010) and thus account for the introduced species found at this site. The stream linking sites 1 and 2 connects to the main NSSF stream at the lower reaches towards the Lorong Banir area, and the topography of the stream might have served as a physical barrier that prevented the introduced species from entering the forested main stream against water flow. The relatively low water temperature and acidic water conditions might also have discouraged the fish from spreading to forested waters. However, we did find a single individual of *Rhinogobius giurinus* at site 10, which is about 300 meters upstream from the exit point to Lorong Banir Stream, suggesting that occasional invasions of such introduced species could happen and persist. Although our current surveys indicated that this species has yet to establish in the main stream, it is no doubt a warning that mitigatory measures must be put in place to prevent such invasions in the future. With the discovery of introduced species at the three localities, it is of great importance to implement preventive measures to reduce the possibility of further alien species from being introduced, in order to safeguard the native species, majority of which were sparsely distributed and by now low in abundance. Possible mitigation procedures might include monitoring and physical removal of the introduced species on a regular basis, as well as the stepping up of existing enforcement in the nature reserves. Enhancing riparian vegetation along the banks of Lorong Banir stream and retaining woody debris in the streams help to preserve the natural habitat of the native species, providing an advantage over invasive alien species which generally prefer disturbed habitats. Construction of artificial barriers can also prevent the infiltration of alien species into the core area of NSSF.

Update on conservation status. Out of the 15 species of nationally threatened freshwater fish listed in The Singapore Red Data Book (Lim et al., 2008), 13 species have been recorded from NSSF in the current survey. Whereas *Trigonostigma heteromorpha* has been listed as 'Endangered' in the Singapore Red Data Book, it occurred at all but one of the sites surveyed in NSSF and in high abundance of average 17 individuals per site per sampling occasion, with the highest being 168 in a single sampling event. Similarly, *Nemacheilus selangoricus*, which was previously listed as 'Critically Endangered', had relatively high mean population abundance and presence at 10 out of 12 sites. Although current results revealed numerical dominance of these species in NSSF, their localisation to Central Catchment Nature Reserve and stringent habitat requirements (in the case of *Nemacheilus selangoricus*) suggest it would be best to retain the current conservation status. More in-depth studies have to be conducted to understand their detailed distribution in the nature reserves. For the remaining 11 species; *Boraras maculatus*, *Desmopuntius hexazona*, *Pangio muraeniformis*, *Pseudomystus leiacanthus*, *Silurichthys hasseltii*, *Parakysis longirostris*, *Clarias nieuhofii*, *Macrognathus maculatus*, *Luciocephalus pulcher*, *Channa gachua*, and *C. melasoma,* the results are consistent with their current national status.

Giam et al (2011) demonstrated through modelling that in Singapore, freshwater fish extinctions appear to depend on local geographic range irrespective of ecological and life history traits. Past developments and habitat loss have directly led to the extinction of 11 species of freshwater fish, of which seven were previously restricted to the swamp forests at Mandai. Comparison of our survey results with published data from aquatic fauna surveys in other areas of the Central Catchment Nature Reserve and Bukit Timah Nature Reserve, as well as other parts of Singapore suggest it is highly possible that *Nemacheilus selangoricus*, *Pangio muraeniformis*, *Pseudomystus leiacanthus*, *Silurichthys hasseltii*, *Parakysis longirostris* and *Macrognathus maculatus*

are currently restricted to NSSF, all of which are forest species dependent on shaded streams with acidic waters. Changes in hydrology and habitat loss might lead to the loss of their entire population, as the dispersal of these species is limited to forested streams within the swamp forest. Hence, conservation efforts should focus on the monitoring and preservation of the NSSF as a hotspot for native freshwater fish diversity. As NSSF is part of the Central Catchment Nature Reserve, it is currently under legal protection by Singapore's National Parks Act (Cap. 198A) and Parks and Trees Act (2005). A multi-disciplinary research project was recently funded to investigate the hydrological and biodiversity baseline, and eco-hydrological models are being developed to facilitate mitigation measures and to establish viable, long-term monitoring programmes to ensure continued protection and good management of NSSF. It is hoped that these measures together with regular enforcement and management by the National Parks Board will promote long-term preservation of the native freshwater fish diversity in NSSF.

CONCLUSION

The last biodiversity assessment of freshwater fish in Nee Soon Swamp Forest was conducted about two decades ago, so results from the current survey are needed to provide a status update, and it also proved useful in addressing gaps in knowledge and making new discoveries for the site. Through the course of the survey, 36 species of freshwater fish have been documented; including 30 native species, one of which was a new record for NSSF, and six introduced species. Of the 15 species listed as "Endangered" or "Critically Endangered" in the Singapore Red Data Book, 13 were found in NSSF, and high local abundance was observed for two of these species. Despite the short time frame, critical aspects of ecology like distribution within NSSF, species diversity and species abundance have been analysed at the respective survey sites and behavioural observations were recorded. These results will serve as important baseline data for further studies. Population dynamics of the fishes have also been studied and will be discussed in a subsequent paper. The updated information can be used in the formulation of conservation measures and establishment of monitoring programs for critically endangered species.

It is hoped that this study will shed light on the rich freshwater fish diversity in NSSF, which is currently under threat from changing hydrological regimes, invasion of introduced species at the outskirts and potential future developments in the areas surrounding the Central Catchment Nature Reserve. Unless measures are taken to safeguard these species, the rich biodiversity and heritage in Nee Soon Swamp Forest might be lost forever.

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LITERATURE CITED

Alfred ER (1966) The freshwater fishes of Singapore. Zoologische Verhandelingen, 78: 1–68.

Baker N (2014) Black snakeheads at Bukit Timah Nature Reserve. Singapore Biodiversity Records, 2014: 273.

Baker N & Lim KKP (2012) Wild Animals of Singapore: A Photographic Guide to Mammals, Reptiles, Amphibians and Freshwater Fishes. Updated Edition. Draco Publishing and Distribution Pte. Ltd. and Nature Society (Singapore), Singapore, 180 pp.

Barel C, Dorit R, Greenwood P, Fryer G, Hughes N, Jackson P, Kawanabe H, Lowe-McConnell R, Nagoshi M, Ribbink A, Trewavas E, Witte F & Yamaoka K. (1985) Destruction of fisheries in Africa's Lakes. Nature, 315: 19–20.

Beaufort LFD (1933) On some new or rare species of *Ostariophysi* from the Malay Peninsula and a new species of *Betta* from Borneo. Bulletin of Raffles Museum, 8: 31–36.

Bleeker P (1851a) Vijfde bijdrage tot de kennis der ichthyologische fauna van Borneo, met beschrijving van eenige nieuwe soorten van zoetwatervisschen. Nat. Tijdschr. Ned. Indie, 2: 415–442.

Bleeker P (1851b) Bijdrage tot de kennis der Chirocentroïdei, Lutodeiri, Butirini, Elopes, Notopteri, Salmones, Echeneoïdei en Ophidini van den Soenda-Molukschen archipel. Verhandelingen van het Bataviaasch Genootschap van Kunsten en Wetenschappen, 24: 1–24.

Bleeker P (1851c) Vijfde bijdrage tot de kennis der ichthyologische fauna van Borneo met beschrijving van eenige nieuwe soorten van zoetwatervisschen. Natuurkundig Tijdschrift voor Nederlandsch Indië, 2: 415–442.

Bleeker P (1852) Zesde bijdrage tot de kennis der ichthyologische fauna van Borneo. Visschen van Pamangkat, Bandjermassing, Praboekarta en Sampit. Natuurkundig Tijdschrift voor Nederlandsch Indië, 3: 407–442.

Bleeker P (1853) Nalezingen op de ichthyologische fauna van het eiland Banka. Natuurkundig Tijdschrift voor Nederlandsch Indië, 5: 175–194.

Bleeker P (1855) Nalezingen op de vischfauna van Sumatra. Visschen van Lahat en Sibogha. Natuurkundig Tijdschrift voor Nederlandsch Indië, 9: 257–280.

Bleeker P (1858) De visschen van den Indischen Archipel. Deel 1. Siluri. Act. Soc. Sei. Indo-Neerl, 4: I–XII, 1–370.

Bleeker P (1875) Gobioideorum species insulindicae novae. Archives Néerlandaises des Sciences Exactes et Naturelles, 10(2): 113–134.

Bloch ME (1792) Naturgeschichte der Ausländischen Fische. Sechster Theil. Morino, Berlin, 126 pp., pls. 289–324.

Bloch ME (1793) Naturgeschichte der Ausländischen Fische. Siebenter Theil. Morino, Berlin, xii+144 pp., pls. 325–360.

Brittan MR (1954a) The cyprinid fish genus *Rasbora* in Malaya. Bulletin of the Raffles Museum, 25: 129–156.

Brittan MR (1954b) A revision of the Indo-Malayan fresh-water fish genus *Rasbora*. Monograph of the Institute of Science and Technology, Manila, 3: 1–224.

Cantor T (1849) Catalog of Malayan fishes. Journal of the Royal Asiatic Society of Bengal, New Ser., 18 (2): I–XII, 983–1443, pls. 1–14.

Corner EJH (1978) The freshwater swamp-forest of South Johore and Singapore. Gardens' Bulletin, Supplement 1: 1–266.

Cuvier G & Valenciennes A (1831) Histoire naturelle des poissons. Tome septième. Levrault, Paris, xxix+531 pp., pls. 170–208.

Cuvier G & Valenciennes A (1832) Histoire naturelle des poissons. Tome huitième. Levrault, Paris, xix+509 pp., pls. 209–245.

Cuvier G & Valenciennes A (1840) Histoire naturelle des poissons. Tome quinzième. Pitois, Paris, xxxi+540 pp., pls. 421–455.

Cuvier G & Valenciennes A (1842) Histoire naturelle des poissons, 16: I–XXII, 1–472 pp., 456–487 pls.

Cuvier G & Valenciennes A (1846) Histoire naturelle des poissons. Tome dix-huitième. Bertrand, Paris, xix+ 505 pp., 520–553 pls.

Duncker G (1904) Die Fische der malayischen Halbinsel. Mitt. Naturh. Mus. Hamburg, 21: 133–207, map 1, text-fig. 1, 1, 2 pls.

Fowler HW (1937) Zoological results of the Third de Schauensee Siamese Expedition, part VIII, – Fishes obtained in 1936. Proceedings of the Academy of Natural Sciences of Philadelphia, 89: 125–264.

Giam XL, Ng TH, Lok AFSL & Ng HH (2011) Local geographic range predicts freshwater fish extinctions in Singapore. Journal of Applied Ecology, 48: 356–363.

Giller PS & Malmqvist B (1998) The Biology of Streams and Rivers. Oxford University Press, Oxford, 304 pp.

Gorman OT & Karr JR (1978) Habitat structure and stream fish communities. Ecology, 59: 507–515.

Gray JE (1830) Illustrations of Indian zoology; chiefly selected from the collection of Major-General Hardwicke. Treuttel, Wurtz, Treuttel & Richter, London & Parbury, Allen and Co., London, Volume 1 (1830–1832): 2pp., 1+100 pls.

Hamilton F (1822) An Account of the Fishes Found in the River Ganges and its Branches. Constable, Edinburgh, 2 Volumes, 405 pp.

Herder F, Schliewen UK, Geiger MF, Hadiaty RK, Gray SM, McKinnon JS, Walter RP & Pfaender J (2012) Alien invasion in Wallace's Dreamponds: records of the hybridogenic "flowerhorn" cichlid in Lake Matano, with an annotated checklist of fish species introduced to the Malili Lakes system in Sulawesi. Aquatic Invasions, 7(4): 521–535.

Herre AWCT (1940) Additions to the fish fauna of Malaya and notes on rare or little known Malayan and Bornean fishes. Bulletin of Raffles Museum, 16: 27–61.

Kottelat M (2013) The Fishes of the Inland Waters of Southeast Asia: A Catalogue and Core Bibliography of the Fishes Known to Occur in Freshwaters, Mangroves and Estuaries. Raffles Bulletin of Zoology, Supplement 27: 1–663.

La Cepède (1800). Histoire naturelle des poissons. Tome second. Plassan, Paris, lxiv+632 pp.

Lakra WS, Sarkar UK, Kumar RS, Pandey A, Dubey VK & Gusain OP (2010) Fish diversity, habitat ecology and their conservation and management issues of a tropical river in Ganga basin, India. Environmentalist, 30(4): 306–319.

Larson HK & Lim KKP (2005) A Guide to Gobies of Singapore. Singapore Science Centre, 164 pp.

Lee PG & Ng PKL (1994) The systematics and ecology of snakeheads in Peninsular Malaysia and Singapore. Hydrobiologia, 285(1): 59–74.

Liew JH & Tan HH (2008) Nee Soon Swamp Forest Under Threat? – Distribution of Introduced Cichlid *Acarichthys heckelii* (Müller and Troschel, 1849) in Singapore's only Remaining Freshwater Swamp Habitat. Unpublished UROPS Thesis. National University of Singapore, Singapore, 24 pp.

Liew JH, Tan HH, Yi Y & Yeo DCJ (2013) Ecology and origin of the introduced cichlid *Acarichthys heckelii* in Singapore's fresh waters – first instance of establishment. Environmental Biology of Fish 97(10): 1109–1118.

Lim KKP (2013) Two syntopic walking catfishes at Upper Seletar. Singapore Biodiversity Records 2013: 92–93.

Lim KKP & Ng PKL (1990) A Guide to the Freshwater Fishes of Singapore. Singapore Science Centre, 160 pp.

Lim KKP, Tan HH & Low JKY (2008) Fishes. In: Davison GWH, Ng PKL & Ho HC (2008) The Singapore Red Data Book. Second Edition. Nature Society (Singapore), pp. 213–244.

Low BW & Lim KKP (2012) Gouramies of the genus *Trichopodus* in Singapore (Actinopterygii: Perciformes: Osphronemidae). Nature in Singapore, 5: 83–93.

Meisner AD (2001) Phylogenetic systematics of the viviparous halfbeak genera *Dermogenys* and *Nomorhamphus* (Teleostei: Hemiramphidae: Zenarchopterinae). Zoological Journal of the Linnaean Society, 133: 199–283.

Nature Society Singapore (2014) A Checklist of the Freshwater Fishes, Amphibians, Reptiles and Mammals of Singapore. http://www.nss.org.sg/documents/VSG%20checklist%20revised.pdf (Accessed 12 June 2014).

Ng HH & Lim KKP (1995) A revision of the Southeast Asian catfish genus *Parakysis* (Teleostei: Akysidae), with descriptions of two new species. Ichthyological Exploration of Freshwaters, 6(3): 255–266.

Ng HH & Tan HH (2010) An annotated checklist of the non-native freshwater fish species in the reservoirs of Singapore. COSMOS, 6(1): 95–116.

Ng PKL, Corlett RT & Tan HTW (eds.) (2011) Singapore Biodiversity: An Encyclopedia of the Natural Environment and Sustainable Development. Editions Didier Millet, Singapore, 552 pp.

Ng PKL & Lim KKP (1989) Rediscovery of the dwarf snakehead, *Channa gachua* Hamilton, 1822 Channidae in Singapore. Raffles Bulletin of Zoology, 37(1): 172–174.

Ng PKL & Lim KKP (1990) Snakeheads (Pisces: Channidae): Natural history, biology and economic importance. In: Chou LM & Ng PKL (eds.) Essays in Zoology: Papers Commemorating the 40th Anniversary of the Department of Zoology, National University of Singapore. Pp. 127–152.

Ng PKL & Lim KKP (1990a) The Black Snakehead, *Channa melasoma* (Bleeker, 1851) (Channidae): First Record from Singapore. Raffles Bulletin of Zoology, 38(1): 21–24.

Ng PKL & Lim KKP (1992) The conservation status of the Nee Soon Freshwater Swamp Forest of Singapore. Aquatic Conservation, Marine and Freshwater Environments, 2: 255–266.

Ng PKL & Lim KKP (1996) The freshwater fishes of Singapore. Journal of the Singapore National Academy of Science, 22–24: 109–124.

Ng PKL & Lim KKP (1997) The diversity and conservation status of fishes in the Nature Reserves of Singapore. In: Chan L & Corlett RT (eds.) Biodiversity in the Nature Reserves of Singapore. National Parks Board, Singapore. Pp. 245–265.

Pallas PS (1770) Spicilegia zoologica quibus novae imprimis et obscurae animalium species iconibus, descriptionibus atque commentariis illustrantur. Fasciculus octavus. Lange, Berlin, 54 pp., 4 pls.

Pusey BJ & Arthington AH (2003) Importance of the riparian zone to the conservation and management of freshwater fish: a review. Marine and Freshwater Research, 54: 1–16.

Rutter C (1897) A collection of fishes obtained in Swatow, China, by Miss Adele M. Fielde. Proceedings of the Academy of Natural Sciences of Philadelphia, 49: 56–90.

Smith HM (1934) Contributions to the ichthyology of Siam. IX–XIX. Journal of the Siam Society, Natural History Supplement, 9 (3): 287–325, pls. 10-14.

Tan HH (2013a) Hasselt's bony-lipped barb at Sime forest. Singapore Biodiversity Records, 2013: 99.

Tan HH (2013b) Hasselt's bony-lipped barb and zebra tilapia at Sime forest. Singapore Biodiversity Records, 2013: 118.

Tan HH & Lim KKP (2008) *Acarichthys heckelii* (Müller & Troschel), an introduced cichlid fish in Singapore. Nature in Singapore, 1: 129–133.

Tan HH & Lim KKP (2011) Rediscovery of the bigmouth stream goby, *Pseudogobiopsis oligactis* (Actinopterygii: Gobiiformes: Gobionellidae) in Singapore. Nature in Singapore, 4: 363–367.

Tan HH & Ng DJJ (2014) Asian arowana in Nee Soon Swamp Forest. Singapore Biodiversity Records, 2014: 25.

Turner IM, Boo CM, Wong YK, Chew PT & Ali bin Ibrahim (1996) Freshwater swamp forest in Singapore with particular reference to that around the Nee Soon firing ranges. Gardens' Bulletin, Singapore, 48(1): 129−157.

Volz W (1903) Neue Fische aus Sumatra. Zoologische Anzeiger, 26: 553–559.

Weber M & de Beaufort LF (1912) Fische. In: Maass A, Durch Zentral Sumatra, 2: 522–541.

Yeo DCJ & Lim KKP (2011) Freshwater ecosystems. In: Ng PKL, Corlett RT & Tan HTW (eds.) Singapore Biodiversity: An Encyclopedia of the Natural Environment and Sustainable Development. Editions Didier Millet, Singapore. Pp. 52–63.