

# **Integrated research, conservation and management of Nee Soon freshwater swamp forest, Singapore: hydrology and biodiversity**

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**ABSTRACT.** The current paper acts as an introduction to nine following papers concerning the hydrology and biodiversity of Nee Soon freshwater swamp forest. Freshwater swamp forest is a threatened and overlooked ecosystem in the Southeast Asian region and in Singapore. Characterised by predominantly mineral soils supporting forest that contains a subset of the flora and fauna of lowland forest, but with the addition of important habitat specialists, freshwater swamp forest is fed by an array of hydrological processes. As conservation management depends on good hydrological and biological understanding, a research programme was designed to tease out the roles of the various hydrological components. The background, management concerns, and aims of the project are detailed.

**Keywords.** Habitat management, project design, project overview, site management

## **Introduction**

Water relations are critical to the global occurrence of tropical evergreen rain forest (Richards, 1952) and to the occurrence, zonation, species composition and ecology of the various rain forest formations such as cloud forest, mangroves and peat swamp forest (e.g. Whitmore, 1984). One of the lesser known tropical forest formations occurring in all three major tropical regions (the Neotropics, Africa, and Asia) is freshwater swamp forest.

Freshwater swamp forest is characterised as forest growing on mineral soils and periodically flooded by fresh water that originates not only from rain; additional sources can include groundwater fluctuations, spill-over of floodwater from adjacent rivers and streams, backflow and a range of other hydrological processes. The forest occurs on soils with an organic content that results in less than 65% loss on combustion (Whitmore, 1984), but this is a somewhat arbitrary as well as generalised distinction from peat swamp forest. In practice, organic content varies through the soil profile with highest levels in the surface humus.

The global and regional importance of freshwater swamp forest, and the national significance of Nee Soon freshwater swamp forest in particular, are reviewed by Clews et al. (2018). Historically, small areas of freshwater swamp forest are thought to have been present in Singapore on the lower reaches of various small river and stream systems, upstream of mangroves, and downstream of dryland forest (Corlett, 1991, 1992). The freshwater swamp forest within each catchment would have been physically and biologically partly isolated from that in other catchments, resulting in local differences in floral and possibly faunal composition.

Corner (1978) began studies of freshwater swamp forest in the Malay Peninsula, including Singapore, around 1932. His work demonstrated the major ecological and floristic features of this forest formation, and indicated floristic differences between the forest at Jurong (now gone, in the vicinity of Jurong Lake Park) and that at Mandai (now gone, but for the currently studied fragment at Nee Soon, in the vicinity of Upper Seletar Reservoir). Turner et al. (1996), Ng & Lim (1992), and Lim et al. (2011) have provided further information on freshwater swamp forest in Singapore and at Nee Soon.

The area within Singapore that is likely to have been primevally under freshwater swamp forest has been variously estimated as 65 km<sup>2</sup> (O'Dempsey, 2014) to 74 km<sup>2</sup> (Corlett, 1991). Of this possibly half was in the catchment of the Kallang and Singapore rivers, one third in the catchment of the Jurong and Pandan rivers, and the remainder scattered in many tiny fragments along the middle courses of small streams prior to them debouching into coastal mangroves.

The relatively intact patch of freshwater swamp forest in Nee Soon has long been considered the most important area in Singapore for native aquatic fauna and flora (Ng & Lim, 1992). Early estimates of its richness suggested that it contains 48% of the primary freshwater fish, 71% of the amphibians, 28% of the reptiles and 34% of the avian fauna of Singapore. Nee Soon is particularly well known for its importance to crustaceans (Ng, 1997; Ng & Yeo, 2005); the freshwater crab *Parathelphusa reticulata* is a global endemic to Nee Soon. The swamp also has the highest percentage of native and threatened freshwater fish species on the island, as well as being the main (if not the only) habitat of the aquatic plant *Barclaya motleyi* Hook.f. By 1992 it was also the last refuge within Singapore of two mammals, the Raffles Banded Langur, *Presbytis femoralis femoralis*, and the Cream-coloured Giant Squirrel, *Ratufa affinis affinis*. The banded langur has gradually increased in numbers and expanded beyond Nee Soon into other parts of the Central Catchment Nature Reserve, whereas the giant squirrel is now thought to have become locally extirpated (Davison et al., 2008).

Study of the swamp forest has until recently been at a survey and discovery phase. Research priorities have been primarily to establish detailed species lists, the status of endangered species and the extent of buffer zones. There has been little documentation of spatial differentiation within the swamp forest.

## Management concerns

The Nee Soon freshwater swamp forest constitutes part of the Central Catchment Nature Reserve, administered primarily by the National Parks Board. The Central Catchment Nature Reserve covers approximately 3,100 hectares (31 km<sup>2</sup>), of which approximately 2,600 hectares are land area and 500 hectares are made up of the surfaces of the MacRitchie, Upper Peirce, Lower Peirce, and Upper Seletar Reservoirs. The land owner is the Public Utilities Board and the land manager is the National Parks Board, but several other government organisations also have limited jurisdiction, causing some complexity in the management of the reserve and the swamp.

Part of the lower catchment is occupied by two firing ranges under the management of the Ministry of Defence and an old disused firing range, now reverted to secondary forest, once existed 0.8 km to the southeast. A water supply pipeline, partly above ground and partly below, runs through the forest, with a grassy side-table for maintenance.

Public access to the nature reserve is limited to designated trails, none of which intrudes into the area of freshwater swamp forest. Visits to the freshwater swamp forest, whether by scientists, educational groups or individuals, are managed by permits. Continuous patrols are not feasible, but legal action against those who infringe regulations can be taken under the Parks and Trees Act (2006).

Past research as well as management have tended to treat the Nee Soon freshwater swamp forest catchment as a single unit without internal differentiation. In fact the Nee Soon stream catchment covers approximately 479 hectares (4.79 km<sup>2</sup>), but the area exhibiting swampy conditions is much smaller. The swampy area is approximately 50 hectares (0.5 km<sup>2</sup>) but cannot be defined exactly because every flood and every dry period differs in extent and duration, streams may become silted, or change course. Criteria for differentiating swampy areas do not exist at this microgeographical scale.

Singapore is deeply conscious of the potential impacts of climate change, including its impacts on biodiversity, and of the role of vegetation as a first line of defence in mitigating impacts (National Climate Change Secretariat, 2016). The National Parks Board therefore has an important part in climate and microclimate mitigation through the management of natural and planted vegetation. This is complementary to its role in the conservation of biological diversity at ecosystem, community, species and population levels, including national obligations under the Convention on Biological Diversity. Recognising the significance of Nee Soon freshwater swamp forest as the home of a large proportion of Singapore's native flora and fauna, managers of the Central Catchment Nature Reserve have been deeply committed to the conservation of this unique ecosystem.

Management initiatives and responses are constrained by shortage of technical information and the granularity of the information. A biodiversity survey of the Bukit Timah and Central Catchment Nature Reserves (covering Nee Soon) in 1993–1997

(Chan & Corlett, 1997; Ng, 1997) included detailed stream mapping (the original hand-plotted maps are kept on file), but longitudinal information on water quality and hydrological changes, and detailed spatial differentiation of plant and animal communities within the Nee Soon stream catchment have been very limited. This has resulted in uncertainties about the existence, magnitude, extent and rate of any changes.

In order to obtain high quality information that would enable the National Parks Board to fulfil its statutory obligations of biodiversity conservation, funds were secured to carry out a multidisciplinary study on the hydrology and biodiversity of Nee Soon freshwater swamp forest.

### **Scoping and project design**

An initial Phase 1 of the project was conducted from January 2011 to March 2012. The aims were:

- i) To establish what we know about Nee Soon freshwater swamp forest in terms of its ground and surface water environment and ecology;
- ii) To characterise the hydrology, geology, topography and flora of the freshwater swamp forest using measurements appropriate for the subsequent development of maps and models;
- iii) To develop a preliminary hydrological model (surface and groundwater flow);
- iv) To conceptualise and test an ecohydrological model characterising interdependence between groundwater flow and vegetation growth.

Phase 2 of the project was conducted from February 2013 to August 2016. The aims were:

- i) To establish the status of Nee Soon freshwater swamp forest in terms of vegetation hydrology and aquatic biodiversity;
- ii) To identify periodic flux in hydrology and key components of the aquatic biodiversity;
- iii) To develop more refined models that can confirm current conditions (water balance, nutrient balance, acid flux, faunal distribution) and then test-trial various management scenarios;
- iv) To identify and assess the root causes of impacts, potential issues that may threaten the hydrological and ecological integrity of the swamp, and management elements to be addressed;
- v) To propose recommendations for possible mitigation of long-term negative impacts;
- vi) To establish a viable, long-term monitoring programme and develop sampling protocols to ensure continued protection and good management;

- vii) To train agency staff in modelling, sampling methods and tools for monitoring;
- viii) To deliver workshops on development and interpretation of the models' outputs;
- ix) To publish work on swamp forest ecology and the development of eco-hydrologic models in international, peer-reviewed scientific journals

Seven teams were formed to conduct the work. They were:

- i) Mapping and geospatial imagery team
- ii) Field hydrology and geomorphology team
- iii) Vegetation ecology team
- iv) Faunal ecology team
- v) Genomics team
- vi) Ecohydrological modelling team
- vii) NParks faunal team and project administration

### **Delivery of results**

Each team produced a three-monthly technical report, consolidated by the project leader into a full quarterly project report. Submission of the draft report to the National Parks Board was followed by a quarterly meeting to discuss past progress and future tasks. After agreement had been reached, each report was accepted with revisions.

Clews et al. (2018) provide a comprehensive review of the global, regional and national significance of freshwater swamp forest. The fundamental geomorphological characteristics and processes are described by Nguyen et al. (2018), as they have profound implications for the hydrology and biodiversity of Nee Soon. Chong et al. (2018) outline some floristic and taxonomic outputs from the project, based on surveys in and beyond 40 quadrats distributed through the drier and wetter areas of Nee Soon. Ho et al. (2018) describe the aquatic macrofauna. Lim et al. (2018) list the molluscs of Nee Soon, and Cai et al. (2018a) the odonates, in the terrestrial and aquatic domains. Kutty et al. (2018) describe the use of next generation sequencing to forge the links between field identifications and image databases of the freshwater swamp forest flora and fauna. Sun et al. (2018) use numerical modelling to describe some of the projected impacts of climate change on stream flow and groundwater conditions. Finally, Cai et al. (2018b) summarise some of the main findings and recommendations arising from the entire project.

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