What are the current trends of biodiversity in Singapore?

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Introduction
Although natural habitat destruction through deforestation is widely recognized as one of the major reasons for the loss of biodiversity in the tropics, the lack of quantitative data - concerning both the changes in biodiversity and the drivers behind this change - makes it difficult to assess the real extent of decline in biodiversity due to land use changes (Sodhi et al., 2004). In contrast, Singapore’s few remaining forest patches have been relatively well studied and the drastic transformation of its land cover has been thoroughly documented. Therefore, Singapore lends itself to serve as a case study to examine the effects of human impacts (i.e. deforestation) on tropical biodiversity (Corlett, 2013).

Questions
How has land use in Singapore changed during the last two centuries and what effects on biodiversity did these changes have?
Does the amount of extinctions that have been recorded match the numbers predicted by the species-area relationship?
What measures have been taken by Singapore to conserve its biodiversity and did they succeed?

Results
Despite recordings of early settlements in the fourteenth century on the island, Singapore was still nearly entirely covered with forest in 1819 when Raffles founded the first British colony (Corlett, 1992). At that time the 544 km² of Singapore (only the main island) were covered with lowland tropical rainforest (82 %), freshwater swamp forest (5 %) and mangroves (13 %) (Turner et al., 1994). After the establishment of the East India Company’s colony the population on the island quickly increased as did hunting pressure and agricultural activities (especially gambier, rubber and prawn farming) so that by 1900 more than 95 % of the primary forest had been destroyed (Corlett, 1992).

The first official forest reserves were installed in 1884 and covered 11 % of the total land area. However, not all of these areas were actually forested and in 1936 their protection status was revoked. After the second world war in 1945, four nature reserves comprising Bukit Timah (66 ha, primary lowland rainforest), the central water catchment area (CWCA) (1622 ha, mostly secondary forest), Labrador (10 ha, cliff area) and sungei buloh (130 ha, mangroves and swamp) were established (Corlett, 1992; Corlett, 2013). Today, about 2400 ha of forest (< 5 % of Singapore’s total area) are left of which only about 200 ha (< 0.4 %) can be considered to be primary forest (mainly at Bukit Timah, Nee Soon and little patches inside the CWCA) (Turner et al., 1994).

Since the start of deforestation in 1819, 881 of Singapore’s total recorded 3’196 species (28 %) have gone locally extinct (only considering species belonging to the well-studied groups of vascular plants, freshwater decapod crustaceans, phasmids, butterflies, freshwater fish, amphibians, reptiles and mammals) (Brook et al., 2003). While some groups like birds suffered more extinctions (34 %), others were less affected (e.g., reptiles: 7 %). Specific traits of certain species also expose them to a higher (or lower) risk of extinction. For example, forest specialists suffered more extinctions (33 %; even 67 % for forest birds (Castelletta et al., 2000)) than open habitat and forest edge specialists (7 %) (Brook et al., 2003). Angiosperms with epiphytic growth, a dioecious reproduction system, a wind based pollination system and a coastal habitat were also positively correlated to the extinction probability (Sodhi et al., 2008).

Based on the area-species relationship Turner et al. (1994) estimated that only 24 % of the original forest flora can persist inside the remaining primary forest. However, this contrasts clearly with the observed 74 % of the native flora that is found to still persist on the Island. This finding corresponds to the observation of other researchers who were surprised by the high biodiversity that continues to
persists despite the large scale destruction of the natural habitats in Singapore (Corlett, 1992). However, reasons other than the high resilience of the ecosystem are discussed below.

(1) The number of species estimated to have been present before 1819 is certainly too low as large scale deforestation started long before the first systematic biodiversity records were made (Brook et al., 2003). To get better estimates of the original biodiversity of Singapore Brook et al. (2003) used data from nearby peninsular Malaysia. From this data an inferred extinction rate of 73 % (up from 28 % when only considering the recorded species) was calculated. By simulating the probability distribution of the extinction rates, the authors show that the true extinction rates probably lies somewhere between the two extremes (~50%).

(2) The number of species still present in Singapore might be overestimated or some populations are not in equilibrium. Sodhi et al. (2008) defined an extinct species as one that has not been sighted in the wild for more than 30 years despite active searching. This illustrates that a species extinction event will always be detected after a time lag and only if researchers actively search for that species.

(3) There are species that still persist but will become extinct in the future due to small population sizes (Brook et al., 2003). For example, half of the tree species present in 4 ha fragment of lowland rainforest belonging to the botanical garden of Singapore were represented by only one or two individuals (Sodhi et al., 2008). On the other hand, a recent study of the genetic diversity of the Koompassia malaccensis (a canopy tree) population in the CWCA did not detect a population bottleneck or a reduced effective population size (Noreen and Webb, 2013). This shows that there is not enough data available yet to quantitatively assess how many species can be considered as “living dead”.

The low temporal resolution in detecting extinction events makes it very difficult to predict the future biodiversity trends in Singapore. However, some measures that are crucial to safeguard Singapore’s biodiversity can be identified. Nearly half of the biodiversity in Singapore occurs exclusively in the protected areas that consist of less than 3 % of the country’s land area (Brook et al., 2003). Therefore the protection of these last reserves is of utmost importance. There are currently no concerns about the protection status of these reserves (Corlett, 2013), however, this might not be enough to prevent the extinction of many species that are currently present in fragmented patches with populations too small to be viable on the long term. Moreover, about half of the well documented species are already considered to be endangered in Singapore (Corlett, 2013). Therefore, the connection of these different forest patches and populations, as well as the restoration of degraded land (often invaded by alien species) will be necessary to provide rare native species with habitat and prevent their extinction (Corlett, 2013; Yong, 2011). The Singaporean government has started to move in this direction, e.g., the park connector network (300 km of length) (Chin, 2008) and the construction of an ecological corridor connecting Bukit Timah and CWCA (Yong, 2011). Other programs exist that target the conservation of a single species (e.g. Oriental pied hornbill, rare dipterocarp species) or a particular ecosystem (e.g. the inter-tidal ecosystems at Chek Jawa) (NParks, 2014). The success of these measures will only be apparent on the long-term, however the fact that extinctions of birds seems to have slowed down and since 2001 no further extinctions have been recorded (Chisholm et al., 2016) can be interpreted as a positive sign.

**Conclusion**

Despite the destruction of 99.6 % of its primary forest and less than 5 % of the land area being forested, Singapore still retains between 27 - 72 % (depending whether inferred extinctions are taken into consideration or not) of its original biodiversity (Brook et al., 2003). Even though there are concerns about the future viability of many species, the example in Singapore illustrates that a large number of species can persist over a long time in a heavily disturbed environment. But it also shows the importance of primary forests, as they host the largest part of the remaining biodiversity despite their tiny size (Corlett, 2013). The destruction of these reserves would have tremendous impacts on Singapore’s biodiversity (Brook et al., 2003).

The time lag of the extinction of many (mainly long lived) species can also be seen as a risk, as it can conceal the true extent of biodiversity loss and an “extinction debt” can be accumulated (i.e. extinctions that will occur as the ecosystems approaches its equilibrium). There are indications than
the rate of extinctions has slowed down and different conservation efforts are underway, however
careful scientific monitoring will be needed to track the success of these measures in the future.

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