The number of insect species on a small oceanic island: two solutions to a Fermi problem

Christopher K. Starr

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Where the number of species of a particular taxon is not sufficiently known even to allow an estimate by extrapolation, the question becomes a Fermi problem. This approach is used to estimate the total species richness of insects on the very small Dutch island of Saba in the Caribbean. Two solutions each lead to estimates of about 8400 or 8500 species. It is suggested that (i) this estimate is probably not very far from the true total, and (ii) reaching a more confident estimate would be a worthwhile project for the Dutch entomological community.

The numbers of species of divers taxa within identified areas are key data in conservation planning. Such species richness is estimated by three basic approaches: (i) Where species (at least as morphospecies) can be distinguished with fair confidence and their absolute numbers are manageable, it may be feasible to use the *brute force method* (my term). In this, specimens are collected and identified until the rate of finding novel species drops to a negligible level. As examples, we are now fairly sure that there are 52 species of social wasps in the West Indies (C.K. Starr unpublished) and close to 10,500 species of birds in the world (del Hoyo *et al.* 2014). (ii) If the history of finding novel species is known and the present rate is relatively low, the *method of extrapolation* (Colwell & Coddington 1994, Mora *et al.* 2011) can serve to estimate the true total within close confidence limits. As an example, 1458 species of flowering plants are now known from Britain, with the total estimated with 95% confidence at 1459 to 1488 (Bebber *et al.* 2007). (iii) Where too little is known to make use of either of these approaches, the question becomes a *Fermi problem* (Weinstein & Adam 2008), solved by means of reasonable estimates of component numbers, together with explicit assumptions. The various estimates of the number of insect species in the world are all examples of this approach, as the accumulation of known species is still much too far from asymptote for extrapolation to yield a meaningful estimate.

The Dutch overseas territory of Saba is a very small oceanic island in the northern Lesser Antilles (17°38'N 63°14'W). It comprises a dormant volcano, Mount Scenery (877 m.), with almost no coastal lowlands (figure 1). It is exceptionally well forested, with a diversity of habitats that include palmbrake and elfin forest (figure 2). Seasonality is quite subdued, with the wettest month (November) having on average only about three times the rainfall of the driest (March) (Saba Conservation Foundation unpublished). Saba's human population of about 2000 is mostly concentrated in four villages.

On a 2016 visit to Saba, the question was put to me how many insect species the island harbours. This is certainly a Fermi problem, as only the butterflies and termites are known to a brute-force level (Smith *et al.* 1994, R.H. Scheffrahn personal communication). Together with the audience at a public lecture, I derived two different estimates of Saba's insect species richness.

Let A, B and I be land area, number of butterfly (Papilionoidea) species and number of insect species, respectively, with subscripts $_c$, $_s$ and $_w$ for Cuba, Saba and the world. The goal, then, is an estimate of the unknown I_s.

In the first treatment, $B_s = 24$ (Smith *et al.* 1994) and $B_w = 13{,}688$ (Shields 1989). Recent estimates of I_w range from 2.5 million to 30 million (reviewed by Starr 2017). Setting the high value aside as an outlier, let us accept the median estimate of 4.8 million. Together with the reasonable (but untested) assumption that butterflies comprise the same fraction of total insect species in Saba as in the world, this yields an estimate of $I_s = I_w(B_s/B_w) = 8496$.

In the second treatment, the fractions of the world's insect fauna present in Cuba, another oceanic island of the Caribbean, is 0.9-4.2% for ten well-studied groups (Odonata, termites, aquatic heteropterans, Lygaeidae, butterflies, skippers, hawk moths, mosquitoes, poneromorph ants and social wasps, figure 3) with a median value of 1.4% (C.K. Starr unpublished). Combining this with the median I_w value of 4.8 million above yields an estimate of $I_c = 67{,}200$. $A_s = 13$ km^2 and $A_c = 114{,}500$, so that $A_s/A_c = 0.0011$ or just about 1/1000. Applying to these two oceanic islands in the Caribbean the biogeographer's rule of thumb that an area ten times as large will have twice as many species (Spiller & Schoener 2009), I_s/I_c is expected to be about 1/8, yielding an estimate of $I_s = 67{,}200/8 = 8400$.

We should not make too much of the near-identity of these two largely independent estimates of Saba's insect species richness. Nonetheless, it is expected that most other estimates by the Fermi approach will not differ very widely from these. For example, if the spider species of Saba (Slowik & Sikes 2011), Cuba (Alayón 1999) and the world (Platnick 2016) are comparably well known, and if the ratios among them approximate those of the insect species of the same areas, we can derive an estimate of I_s not very different from the two above. This gives added confidence that we are not far from the true value of I_s.

However, my main purpose here is not to furnish a particular estimate of this value but to facilitate its supersedure by a

1. Aerial view of Saba to illustrate its small size, rugged topography and virtual lack of coastal lowlands. Photo: Saba Freediving School (www.sabafreediving.com)
1. Luchtfoto van Saba waarbij het kleine oppervlak, de flinke hoogteverschillen en het vrijwel ontbreken van kustlaagland zichtbaar zijn.

more exact estimate. I_s appears to be on a modest enough scale that the number of known species could be brought within reach of the extrapolation approach. An intensive recent effort to collect the spiders of Saba (Slowik & Sikes 2011) allows a rough estimate of the labour required to collect and sort to morphospecies most of the insects. These authors devoted about 50 person-hours to collecting 76 species of spiders and about 25 hours to separating them to morphospecies (J. Slowik personal communication). If there are 100 times as many insect as spider species on Saba, it would require about 7500 person-hours or two person-years to collect and sort most of them. With that done, approach 2 above could be applied to estimating I_s within fairly narrow confidence limits. A significant part of this has already been done, as Slowik & Sikes's (2011) study was part of a broader effort to collect and identify Saba's land arthropods.

I draw this to the attention of the government and entomological community of the Netherlands as a worthwhile, feasible and cost-effective national project. It bears mention that the nearby Dutch territory of Sint Eustatius (17°29'N 62°59'W, 21 km^2) is expected to have a similar total insect species richness and much the same species inventory, so that a combined treatment of the two islands together would certainly introduce a substantial economy of scale.

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2. Elfin forest near the peak of Mount Scenery on Saba. Photo: Jinze Noordijk
2. Dwergbomenbos nabij de top van Mount Scenery op Saba.

3. Saba's only social wasp, *Polistes crinitus* (Felton, 1765), is found in most of the northern Lesser Antilles. Photo: Christopher K. Starr
3. De enige sociale wesp op Saba, *Polistes crinitus* (Felton, 1765), komt voor op de meeste eilanden van de noordelijke Kleine Antillen.

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Samenvatting

Het aantal insectensoorten op een klein oceanisch eiland: twee oplossingen voor een Fermi-probleem

Als het aantal soorten van een bepaald taxon niet voldoende bekend is om er zelfs door middel van extrapolatie een schatting van te kunnen maken, dan wordt de uitkomst een Fermi-probleem; een berekening die vraagt om een benadering op basis van enkele geschatte aantallen. Deze aanpak is gebruikt om het aantal insectensoorten op het zeer kleine eiland Saba in Caribisch Nederland te schatten. Twee verschillende rekenwijzen komen beide uit op 8400 tot 8500 soorten. In dit artikel wordt gesuggereerd dat deze schatting waarschijnlijk niet sterk afwijkt van het daadwerkelijke aantal, en dat het bepalen van een nog betrouwbaardere schatting een waardevol project is voor Nederlandse entomologen.

Christopher K. Starr
University of the West Indies
c/o Department of Life Sciences
St Augustine
Trinidad & Tobago
ckstarr@gmail.com