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Integrated disease mapping in a polyparasitic world

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Malaria and the neglected tropical diseases

In the past, and still today, people living in the developing world have been, and continue to be, repeatedly exposed to a number of endemic parasitic diseases which impose an intolerable economic, health and social burden on their societies (Stoll, 1947; Sachs and Malaney, 2002). Among the parasitic diseases, malaria due to *Plasmodium falciparum* inflicts the largest burden (Snow et al., 2005). Concurrently, hundreds of millions of people are plagued by a number of so-called neglected tropical diseases (NTDs). The most significant of these are Chagas disease in South America, human African trypanosomiasis, leishmaniasis, lymphatic filariasis, onchocerciasis, schistosomiasis, soil-transmitted helminthiasis and trachoma. The scale of the problem is illustrated in Table 1, which summarises current population statistics, including at-risk populations, estimated numbers of people infected, annual morbidity and mortality rates and burden estimates due to malaria and the above-mentioned NTDs.

In recent years, there has been an upsurge in public and private spending in global health, with particular efforts aimed at tackling HIV/AIDS, tuberculosis and malaria (Lu et al., 2006). With enhanced funding coming on stream also for the NTDs, new partnerships and global alliances have been formed to tackle a number of NTDs, with preventive chemotherapy playing a key role (Brady et al., 2006; Hotez et al., 2006; WHO, 2006). This funding has coincided with calls to improve the coordination and integration of national control programmes, placing emphasis on simultaneous morbidity control due to NTDs (e.g. schistosomiasis and soil-transmitted helminthiasis) or to eliminate NTDs as a public-health problem (e.g. lymphatic filariasis) (Brady et al., 2006; Lammie et al., 2006). To help allocate public-health resources, an essential first step is to delineate and understand the spatial distribution of different parasitic diseases (Brooker et al., 2006; Hay and Snow, 2006; Utzinger and de Savigny, 2006).

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Mapping and prediction of co-endemic areas

The need

Parasite transmission intensity exhibits significant spatial and temporal heterogeneity and, because of their neglected nature, there exists limited information about the exact geographical distribution of most of the NTDs, as well as malaria (Polack et al., 2005; Hay and Snow, 2006). It follows that the spatial congruence of different NTDs, as well as of

Table 1. Current global estimates of populations at risk, number of people infected and suffering from morbidity, and annual mortality rates and burden estimates of malaria and selected NTDs (DALY, disability-adjusted life year; NA, not applicable; ND, not determined). The DALY is a summary measure of disease burden that combines the impact of illness, disability and mortality on population health and was last estimated by the World Health Organization in 2002 (http://www.who.int/health-info/bod/en/index.html).

Disease	Causative agent(s)	Population at risk (x 10^6)	People infected (x 10^6)	Morbidity (x 10^6)	Mortality (x 10^3)	Burden (x 10^6 DALYs)	Reference
Malaria	*Plasmodium falciparum, P. malariae, P. ovale, P. vivax*	2211	NA	515	1272	46.49	WHO, 2004; Snow et al., 2005
Soil-transmitted helminthiasis							
Ascariasis	*Ascaris lumbricoides*	4211	807-1221	350	3-60	1.82-10.5	Bethony et al., 2006; Lammie et al., 2006
Hookworm disease	*Ancylostoma duodenale, Necator americanus*	3195	576-740	150	3-65	0.06-22.1	Bethony et al., 2006; Lammie et al., 2006
Trichuriasis	*Trichuris trichiura*	3212	604-795	220	3-10	1.01-6.4	Bethony et al., 2006; Lammie et al., 2006
Strongyloidiasis	*Strongyloides stercoralis*	ND	30-100	ND	ND	ND	Bethony et al., 2006
Lymphatic filariasis	*Wuchereria bancrofti, Brugia malayi, B. timori*	>1000	120	43	0	5.78	Lammie et al., 2006
Schistosomiasis	*Schistosoma haematobium, S. intercalatum, S. japonicum, S. mansoni, S. mekongi*	779	207	120	15-280	1.7-4.5	Lammie et al., 2006
Trachoma	*Chlamydia trachomatis*	ND	150	ND	0	2.33	WHO, 2004
Onchocerciasis	*Onchocerca volvulus*	120	18	ND	0	0.48	Watkins, 2003; WHO, 2004
Leishmaniasis	*Leishmania donovani, L. chagasi, L. infantum*	350	12	ND	51	2.09	Watkins, 2003; WHO, 2004
Human African trypasosomiasis	*Trypanosoma brucei gambiense, T. b. rhodesiense*	>60	0.5	ND	50	1.53	Watkins, 2003; WHO, 2004
Chagas disease	*Trypanosoma cruzi*	120	11-18	ND	13	0.67	Watkins, 2003; WHO, 2004

NTDs and *P. falciparum* malaria, remains poorly defined. On the other hand, significant progress has been made with a number of geospatial tools, such as geographical information systems (GIS), remotely-sensed environmental data, and geostatistics that allow to better describe, understand and predict the geographical distribution of single NTDs (Malone, 2005; Yang et al., 2005; Brooker, 2007). Ultimately, these geospatial tools offer the potential to improve the spatio-temporal targeting of control measures and to enhance the cost-effectiveness of integrated disease control programmes.

The proposal

In the context of integrated disease control, we propose that the spatial co-distribution of different parasite species over large geographical areas, such as at continental scales, can be based initially on climate-based disease risk maps (Brooker et al., 2006). Such maps, however, belie the geographical variation of co-distribution and co-infection evident at community and district levels, which is difficult to capture with existing risk models. To date, only one study has attempted to analyse the spatial occurrence of co-infection at a small spatial scale (an area of 40 x 60 km) within a single district of a West African country (Raso et al., 2006). This study showed that it was possible to predict spatial patterns of *Schistosoma mansoni*-hookworm co-infections. Future similar work for different parasite species in varying transmission settings, coupled with an improved understanding of spatial risk factors of different parasite species will allow the projection of co-endemicity on the basis of remotely-sensed satellite data, as well as behavioural, demographic, epidemiological and socio-economic risk factors. Such research will aid the development of risk maps which can identify large-scale patterns of potential overlap, and thus guide regional and national level integrated disease control efforts.

At finer scales, on the other hand, there remains a need to undertake rapid and inexpensive assessments of infection levels to guide local control. Table 2 summarises different approaches that have been developed and successfully validated for the rapid assessment of different NTDs. For example, a simple morbidity questionnaire administered through the existing education system allows the rapid delineation of high-risk areas of schistosomiasis haematobia, based on the specific symptomatology of *Schistosoma haematobium*, which is the presence of blood in urine (Lengeler et al., 2002). With regard to lymphatic filariasis, onchocerciasis and visceral leishmaniasis, accurate, non-invasive, rapid antigen detection assays applicable under field conditions have become available (Weil et al., 1997; Ayong et al., 2005; Chappuis et al., 2006). In the case of lymphatic filariasis, mapping of disease distributions has been based on the use immunochro-

Table 2. Tools currently available for rapid and inexpensive assessment of high-risk communities, and hence for mapping purposes, of a number of NTDs.

Disease	Causative agent(s)	Rapid assessment approach	Reference
Schistosomiasis	*Schistosoma haematobium*	Morbidity questionnaires: reported blood in urine	Lengeler et al., 2002
	Schistosoma mansoni	Morbidity questionnaires: reported blood in stool	Lengeler et al., 2002
		Close proximity to lakes (< 5 km)	Lengeler et al., 2002
		Lot quality assurance sampling	Brooker et al., 2005
	Schistosoma japonicum	Morbidity questionnaires: reported blood in stool	Zhou et al., 1998
Lymphatic filariasis	*Wuchereria bancrofti*	Antigen detection assay: ICT	Weil et al., 1997
		Lot quality assurance sampling	Vanamail et al., 2006
Leishmaniasis	*Leishmania donovani, L. chagasi, L. infantum*	Antigen detection assay: K39 strip test	Chappuis et al., 2006
Onchocerciasis	*Onchocerca volvulus*	Antigen detection assay: Oncho-dipstick test	Ayong et al., 2005

matographic card tests (ICT) for the detection of circulating antigen from adult *Wuchereria bancrofti* filarial antigenaemia in order to target mass drug administration (Gyapong et al., 2002).

Recent operational research has also highlighted the potential of lot quality assurance sampling of a small number of individuals attending primary schools for identifying high-risk communities for schistosomiasis mansoni (Brooker et al., 2005) and for monitoring lymphatic filariasis control programmes (Vanamail et al., 2006). Further investigation and comparison of the cost-effectiveness of different rapid mapping approaches, used singly or in combination, is clearly warranted. We conjecture that it should be possible to integrate the rapid mapping of different NTDs simultaneously with tools that are already available, and that this is an area which merits investigation.

Challenges and opportunities

A major challenge for such geospatial research will be to integrate the disease-specific ecologies and epidemiologies of different parasite species and vector/intermediate host species, as well as contextual determinants (e.g. behaviour, density and migration patterns of humans and socio-economic status) into a single analytical framework. For example, recent studies have highlighted intrinsic differences in the spatial heterogeneity of specific diseases depending on the eco-epidemiological and socio-cultural setting (Gyapong et al., 2002; Brooker et al., 2004). Hence, understanding the complexity of risk factors of co-distribution and co-infection require detailed field studies, including validation of generated risk maps of co-infections. The studies will also necessitate the development of new geostatistical methods, building on the successful application of Bayesian geostatistical approaches in modelling spatial distributions of single parasite species (Gemperli et al., 2004; Raso et al., 2005; Clements et al., 2006).

Finally, the development of an integrated approach to map and predict a number of different NTDs simultaneously would require careful consideration of the different spatial heterogeneities of different species and over what spatial scale variation occurs, as well as simulation studies to determine the optimal sample size to capture species-specific epidemiological patterns.

Concluding remarks

As public-health resources are increasingly available to address global health issues as part of unprecedented efforts to meet international development goals, large-scale control efforts get underway, most recently also to tackle NTDs. The initiation of such control does not, however, signal the end of geospatial research rather underscores its vital importance. Numerous geospatial issues require attention, including geostatistical techniques that should go hand-in-hand with field studies and operational research, thus requiring collaboration among geospatial scientists and public-health specialists. Such work will determine whether research can have a real public-health impact rather than remain only an academic exercise.

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References

Ayong LS, Tume CB, Wembe FE, Simo G, Asonganyi T, Lando G, Ngu JL, 2005. Development and evaluation of an antigen detection dipstick assay for the diagnosis of human onchocerciasis. Trop Med Int Health 10, 228-233.

Bethony J, Brooker S, Albonico M, Geiger SM, Loukas A, Diemert D, Hotez PJ, 2006. Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. Lancet 367, 1521-1532.

Brady MA, Hooper PJ, Ottesen EA, 2006. Projected benefits from integrating NTD programs in sub-Saharan Africa. Trends Parasitol 22, 285-291.

Brooker S, 2007. Spatial epidemiology of human schistosomiasis in Africa: risk models, transmission dynamics and control. Trans R Soc Trop Med Hyg 101, 1-8.

Brooker S, Clements ACA, Hotez PJ, Hay SI, Tatem AJ, Bundy DAP, Snow RW, 2006. The co-distribution of *Plasmodium falciparum* and hookworm among African schoolchildren. Malar J 5, 99.

Brooker S, Kabatereine NB, Myatt M, Stothard JR, Fenwick A, 2005. Rapid assessment of *Schistosoma mansoni*: the validity, applicability and cost-effectiveness of the lot quality assurance sampling method in Uganda. Trop Med Int Health 10, 647-658.

Brooker S, Kabatereine NB, Tukahebwa EM, Kazibwe F, 2004. Spatial analysis of the distribution of intestinal nematode infections in Uganda. Epidemiol Infect 132, 1065-1071.

Chappuis F, Rijal S, Soto A, Menten J, Boelaert M, 2006. A meta-analysis of the diagnostic performance of the direct agglutination test and rK39 dipstick for visceral leishmaniasis. BMJ 333, 723.

Clements ACA, Moyeed R, Brooker S, 2006. Bayesian geostatistical prediction of the intensity of infection with *Schistosoma mansoni* in East Africa. Parasitology 133, 711-719.

Gemperli A, Vounatsou P, Kleinschmidt I, Bagayoko M, Lengeler C, Smith T, 2004. Spatial patterns of infant mortality in Mali: the effect of malaria endemicity. Am J Epidemiol 159, 64-72.

Gyapong JO, Kyelem D, Kleinschmidt I, Agbo K, Ahouandogbo F, Gaba J, Owusu-Banahene G, Sanou S, Sodahlon YK, Biswas G, Kale OO, Molyneux DH, Roungou JB, Thomson MC, Remme J, 2002. The use of spatial analysis in mapping the distribution of bancroftian filariasis in four West African countries. Ann Trop Med Parasitol 96, 695-705.

Hay SI, Snow RW, 2006. The malaria atlas project: developing global maps of malaria risk. PLoS Med 3, e473.

Hotez PJ, Molyneux DH, Fenwick A, Ottesen E, Ehrlich Sachs S, Sachs JD, 2006. Incorporating a rapid-impact package for neglected tropical diseases with programs for HIV/AIDS, tuberculosis, and malaria. PLoS Med 3, e102.

Lammie PJ, Fenwick A, Utzinger J, 2006. A blueprint for success: integration of neglected tropical disease control programmes. Trends Parasitol 22, 313-321.

Lengeler C, Utzinger J, Tanner M, 2002. Questionnaires for rapid screening of schistosomiasis in sub-Saharan Africa. Bull World Health Organ 80, 235-242.

Lu CL, Michaud CM, Khan K, Murray CJL, 2006. Absorptive capacity and disbursements by the Global Fund to Fight AIDS, Tuberculosis and Malaria: analysis of grant implementation. Lancet 368, 483-488.

Malone JB, 2005. Biology-based mapping of vector-borne parasites by geographic information systems and remote sensing. Parassitologia 47, 27-50.

Polack S, Brooker S, Kuper H, Mariotti S, Mabey D, Foster A, 2005. Mapping the global distribution of trachoma. Bull World Health Organ 83, 913-919.

Raso G, Matthys B, N'Goran EK, Tanner M, Vounatsou P, Utzinger J, 2005. Spatial risk prediction and mapping of *Schistosoma mansoni* infections among schoolchildren living in western Côte d'Ivoire. Parasitology 131, 97-108.

Raso G, Vounatsou P, Singer BH, N'Goran EK, Tanner M, Utzinger J, 2006. An integrated approach for risk profiling and spatial prediction of *Schistosoma mansoni*-hookworm coinfection. Proc Natl Acad Sci USA 103, 6934-6939.

Sachs J, Malaney P, 2002. The economic and social burden of malaria. Nature 415, 680-685.

Snow RW, Guerra CA, Noor AM, Myint HY, Hay SI, 2005. The global distribution of clinical episodes of *Plasmodium falciparum* malaria. Nature 434, 214-217.

Stoll NR, 1947. This wormy world. J Parasitol. 33, 1-18.

Utzinger J, de Savigny D, 2006. Control of neglected tropical diseases: integrated chemotherapy and beyond. PLoS Med 3, e112.

Vanamail P, Subramanian S, Srividya A, Ravi R, Krishnamoorthy K, Das PK, 2006. Operational feasibility of lot quality assurance sampling (LQAS) as a tool in routine process monitoring of filariasis control programmes. Trop Med Int Health 11, 1256-1263.

Watkins BM, 2003. Drugs for the control of parasitic diseases: current status and development. Trends Parasitol 19, 477-478.

Weil GJ, Lammie PJ, Weiss N, 1997. The ICT filariasis test: a rapid-format antigen test for diagnosis of bancroftian filariasis. Parasitol Today 13, 401-404.

WHO, 2004. The world health report 2004: changing history.

World Health Organization, Geneva.

WHO, 2006. Preventive chemotherapy in human helminthiasis. Coordinated use of anthelmintihic drugs in control interventions: a manual for health professionals and programme managers. World Health Organization, Geneva.

Yang GJ, Vounatsou P, Zhou XN, Utzinger J, Tanner M, 2005. A review of geographic information system and remote sensing with applications to the epidemiology and control of schistosomiasis in China. Acta Trop 96, 117-129.

Zhou H, Ross AGP, Hartel GF, Sleigh AC, Williams GM, McManus DP, Luo XS, He Y, Li YS, 1998. Diagnosis of schistosomiasis japonica in Chinese schoolchildren by administration of a questionnaire. Trans R Soc Trop Med Hyg 92, 245-250.