APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS TO CO-ANALYSIS OF DISEASE AND ECONOMIC RESOURCES: DENGUE AND MALARIA IN THAILAND

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Abstract. Two vector-borne communicable diseases, malaria and dengue, are among a number of diseases of particular importance in relation to economic development in Southeast Asia and thus need to be assessed in relation to economic parameters in the region. Geographical Information Systems (GIS) provide one means of comparing disease and resource data *versus* time and place, to facilitate rapid visualization by planners and administrators. Given that Thailand is a global epicenter of multidrug resistant falciparum malaria and of dengue hemorrhagic fever, both of which are mosquito-borne, application of GIS methods to these two diseases gives opportunity for comparison of resource needs and allocation in relation to disease epidemiologic patterns. This study examined per capita gross provincial product (GPPpc) and health care resources in relation to geographic distribution of malaria and dengue in Thailand. The two diseases vary greatly in overall seasonal patterns and in relation to provincial economic status, and present differing demands on resource utilization: planned integration of control of malaria and dengue could utilize such analyses in relation to resource sharing and consideration of allocative efficiency. The concentration of malaria (and to a lesser extent dengue) along international border areas underscores the desirability of multi-country coordination of disease management and control programs. Because socio-economic and disease data are collected by quite different means and in different time frames, there are some limitations to the dynamic interpolation of these two broad data sets, but useful inferences can be drawn from this approach for application to overall planning, at both national and multi-country levels.

INTRODUCTION

Delineating the relationship between economic development and health is complex, ideally involving multi-parameter analysis at both macro and micro levels. A particularly vital interface is that between macroeconomic planners and health systems operational management: beyond a budget line item health too rarely has a voice in the overall national economic planning process, yet it has or should have a decisive impact on many facets of this process. Appropriate presentation of databases is one positive element that can facilitate understanding of the linkage between resources, development planning, health care and productivity potential: this presentation needs to be clear and rapid. At both national and local levels geographical information systems (GIS) offer one such facilitation mechanism. Most commonly in the health sector context GIS are applied to the interaction between physical environment and disease epidemiology, but interfacing economic parameters may also be directly useful for the challenges of development planning, promoting rapid visual appreciation of differing data inputs. Such an approach requires consideration of the sources and time frame of different data sets, as well as the geographical units on which each pool of information is based. This study represents a start in this direction, with consideration of two vector-borne diseases, malaria and dengue fever, that are of special importance in Southeast Asia, which is a global epicenter of multidrug resistant falciparum malaria and of dengue hemorrhagic fever. The study looks at these two communicable diseases in relation to some selected economic factors in Thailand, as a model

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for potential, wider regional analyses that could help to encourage inter-country collaboration in communicable disease control.

Some in-depth assessments have been made of cost effectiveness of control of malaria (Kaewsonthi, 1991) and dengue (Okanurak *et al,* 1997) in Thailand but translating the outcomes into continuing public health policy can be greatly improved by appropriate approaches to multifactorial data handling in a format that is mutually understandable by both fiscal planners and health planners. Severe malaria and the severe form of dengue both represent serious, potentially fatal problems and thus are critical parts of the national disease burden. Like many communicable diseases they are subject to periodic epidemic expansion, particularly with high rates of population movements within and between neighboring countries. Exploring the potential of GIS methods for handling multiple data sources in an easily comprehended fashion can contribute to improved strategies of economically feasible disease management.

METHODS

Data sources

Incidence data on malaria and dengue were obtained from the annual records of the respective Divisions of the Department of Communicable Disease Control, Ministry of Public Health (MOPH), Thailand, per internet database. While much more detailed databases (*eg* parasite and vector species, specialized malaria clinic distribution) are available the data for entry here were limited in order to simplify associations with economic parameters. These databases are upgraded frequently (weekly/monthly) from case reports; here use has been made of monthly and yearly data.

Health resource data (physicians, nurses, hospital beds) were obtained from the Personnel Department, MOPH, Thailand per internet database. To permit analysis alongside economic parameters only data for the year 1995 were used in this study. Similarly health and welfare data were obtained from the Social Security Office, Ministry of Labor and the Social Insurance Office, MOPH, Thailand.

Data on Gross Provincial Product (GPP) were obtained from the National Statistical Office (NSO) and National Economic and Social Development Board of Thailand: these data are derived from household surveys conducted nationally every two years. GPP data were combined with provincial population data from the NSO to provide GPP per capita (GPPpc). Because of the quite different basis and frequency of disease and economic data derivation, comparison of the two broad data sets has been restricted in this presentation to a single year (1995) for which most data are available.

All databases were entered in Excel format for application to mapping programs.

Mapping

Pertinent mapping inputs have been derived from a variety of official and unofficial sources to produce the map of Thailand in MapInfo software format. Use has been made of regional map profiles developed by the Australian Center of the Asian Spatial Information and Analysis Network (ACASIAN) (Stern and Crissman, 1988): these maps were developed in ArcInfo and transposed into MapInfo format. The maps do not show available information on geographical features (*eg* mountain ranges, forests) which are relevant to vector-borne disease distribution [(*cf* Hu *et al,* 1998)] on GIS analysis of malaria in Yunnan Province, China] since these factors are outside the immediate focus of interest in comparing simplified economic and disease patterns.

MAP PROFILES

Regional context and provincial population distribution

Thailand is one of a cluster of countries which together form the so-called Mekong region of Southeast Asia (Fig 1). This cluster is taken here to include two southern provinces of China, Yunnan Province and Guangxi Juang Autonomous Region, since they share international boundaries with some of the other countries, even though the Mekong River does not flow through Guangxi. Both provinces have large minority populations with close affinity to population groups in neighboring Mekong countries, underscoring the importance of taking a holistic view rather than a narrow national one in examining disease patterns in this region. Thus

Thai data are to be interpreted in the context of the national cluster and the role of the international boundaries.

Although the Thai provincial (changwat) level is taken as a convenient unit for analysis, population is unevenly distributed in the 77 provinces (Fig 1, Table 1). There are large urban clusters, with Bangkok (4) at one extreme having more than 6 million, while at the other extreme provinces such as Mae Hong Son (37) or Ranong (73) have less than one twentieth that population. The overall pattern is changing rapidly, with considerable intra-country redistribution occurring as employment opportunities arise or disappear. Thus the mapped profile should be taken as an approximation only, especially as census data are gathered infrequently (every 10 years) and a large proportion of the population retain official domicile registration in their home-town rather than their work/dwelling place. Nevertheless, the diversity of population distribution is an important consideration in relation to both disease and economic analysis.

Dengue case distribution

Two different sets of data are presented for the distribution of dengue fever: yearly for the 6 years from 1992 to 1997 (Fig 2) and monthly for the single year 1995 (Fig 3), expressed as a proportion of population affected in each province. The yearly data show remarkable variation from one twelve month period to the next, with large regions comprising province clusters changing in overall incidence. The same changing pattern can be observed over an even longer time frame, so that epidemiologic analysis best utilizes data averaged over about ten years (Chunsutthiwat, personal communication). Given that dengue viruses constitute a family of four serotypes, each of which comprises a large number of structural variants, this is not surprising in view of the complexity of community-based immunity or immune enhancement (Kurane *et al,* 1994). The monthly pattern (Fig 3) shows clear seasonality, with the high period in the middle months encompassing the rainy season and the low period covering the cool season.

Malaria case distribution

In contrast to dengue, malaria distribution shows less variability over the 6 year period 1992-1997 (Fig 4). The pattern, expressed as a proportion of population affected in each province, reflects a degree of stabilization of higher or lower frequency in broad regions of the country. Particularly persistent higher frequencies are evident in many of the western provinces that share or are located near to the international border with Myanmar and to a lesser extent in the east near the Lao PDR and Cambodian borders. Although there is some seasonal variation (Fig 5) in the monthly pattern in 1995 this is much less marked than in the case of dengue. Both are dependent for transmission on mosquito vectors but these belong to quite different genera/species with different breeding sites and differing behavior. It should be noted that these data reflect the sites where malaria cases are diagnosed and treated; in view of the high population mobility between provinces because of employment shifts, mapping of disease on the basis of province of origin may give rather different profiles.

Disease and wealth/poverty distribution

Mapping GPPpc on a provincial basis gives one perspective of wealth/poverty distribution. GPPpc varies over a ten-fold range based on 1995 data (Fig 6). There is a concentration of wealth in Bangkok and surrounding provinces, but it is not limited to this area. The northeast cluster of provinces are the poorest. What is dramatically reinforced in this map format is the striking difference in the incidence patterns of malaria and dengue. While dengue is widely distributed, malaria is heavily concentrated along or near the international border with Myanmar. Neither disease shows a clear predilection for poorer or richer provinces, but of the two diseases, the dengue case load in 1995 tended to be greater in some provinces with low GPPpc. On the basis of this relative wealth index it may perhaps be surprising to observe that the frequency of malaria, which attracts a global designation as a disease of poverty (Indaratna and Kidson, 1995; Kidson and Indaratna, 1998), does not bear any clear relationship to poverty at the gross level of GPP. The pattern is dominated by the proximity of provinces to international border regions, suggesting that population movement is a major factor in disease transmission. Differential presence of malaria vectors will also be a critical factor, *ie* predilection of *Anopheles dirus* for border areas by virtue of its forest breeding areas ecological habitat. The data shown in Fig 6 are for Thai malaria cases only. Records of malaria cases among nationals and foreigners are recorded separately, allowing

Table 1

Names of Thai provinces corresponding to code numbers given in Fig 1.

No.	Name	No.	Name
61	Amnat Charoen	43	Phayao
9	Ang Thong	22	Phetchaburi
4	Bangkok	35	Phetchabun
50	Buri Ram	34	Phitsanulok
1	Chai Nat	5	Phra Nakhon Si Ayutthaya
10	Chathaburi	36	Phrae
46	Chaiyaphum	33	Phichit
29	Chiang Mai	15	Prachin Buri
28	Chiang Rai	71	Phuket
12	Chon Buri	21	Prachuap Khiri Khan
64	Chumphon	73	Ranong
44	Kalasin	23	Ratchaburi
27	Kamphaeng Phet	16	Rayong
19	Kanchanaburi	52	Roi Et
45	Khon Kaen	55	Sakon Nakhon
63	Krabi	17	Samut Prakan
38	Lampang	25	Samut Sakhon
39	Pamphun	24	Samut Songkhram
53	Loei	7	Saraburi
6	Lop Buri	75	Satun
37	Mae Hong Son	76	Surat Thani
51	Mahara Sarakham	8	Sing Buri
60	Mukdahan	54	Si Sa Ket
14	Nakhon Nayok	74	Songkhla
48	Nakhon Phanom	18	Sa Kaeo
49	Nakhon Ratchasima	40	Sukhothai
20	Nakhon Pathom	26	Suphan Buri
31	Nakhon Sawan	56	Surin
66	Nakhon Si Thammarat	30	Tak
32	Nan	65	Trang
67	Narathiwat	13	Trat
62	Nong Bua Lam Phu	59	Ubon Ratchathani
57	Nong Khai	58	Udon Thani
2	Nonthaburi	42	Uthai Thani
3	Pathum Thani	41	Utaradit
68	Pattani	72	Yala
69	Phangnga	47	Yasothon
70	Phatthalung		

separate analysis: when malaria cases among foreigners are mapped we find that the incidence is also concentrated along international borders: Myanmar, Cambodia, Lao PDR (Fig 7). Given that the Thai government policy is to consider management of malaria as a public good and thus to offer " free" treatment to nationals and foreigners alike, this pattern is not surprising, since it reflects in part a flow of individuals crossing borders to seek this treatment from clinical facilities in close proximity to their places of residence or work.

Resource distribution

Gross provincial product per capita is a broad economic measure of the geographical distribution of financial resources among the population in public and private sectors combined. It does perhaps permit at a glance some superficial assessment of employment and business opportunities. It may also reflect the potential capacity of the population to contribute to the immediate payment of medical costs and of the capacity of the provincial administration to support the infrastructure pertinent to accessibility to health services. Another more focused approach to resource availability is to look at distribution of resources directly related to the health services themselves, such as physicians, nurses and hospital beds. These are plotted on the basis of population number per item in Fig 8 against the more general parameter, GPPpc, for the year 1995. Immediately apparent is the concentration of nurses and physicians in the Bangkok metropolitan area; disproportionate distribution of health care personnel is present but less marked in some other provinces, including those (Chiang Mai, Khon Kaen, Songkhla) with academic medical institutions but not restricted to those sites. On the other hand there is a relative deficit of health care personnel in the poorer northeast provinces. There is considerable heterogeneity in distribution of hospital beds on a provincial/population basis, with no clear pattern emerging when comparison is made of relationship to GPPpc. These data encompass both public and private hospitals, but private hospitals tend to congregate in major urban areas. No distinction is made here between regional, provincial and district hospitals, nor are health center facilities included in these figures. Then, too, the existence of hospital beds does not necessarily bear any direct relationship to outpatient facilities, nor does it give any indication of accessibility of populations or population economic subgroups to these facilities in terms of existence of necessary infrastructure or affordability of use.

Insurance against health care costs

A major determinant of health care accessibility is cost to the patient. In economies where health care cost is not universally covered by a tax-based mechanism, one way of looking at this factor is to determine the extent of population coverage by health insurance. In Thailand only about half of the population is covered by one or other insurance system, of which there are several (Indaratna and Hutubessy, 1998). We depict here three main categories of public health insurance: the Social Security Scheme, the Health Card Scheme and Welfare which cover different population subgroups. The Social Security Scheme compulsorily covers non-work related health problems in the workforce, the Health Card Scheme which involves voluntary payment of a subscription fee, is intended to cover many of those not covered by the Social Security Scheme. Welfare covers a number of schemes including the Low Income Card elderly population and the under 12 and the Civil Servant Benefit Scheme. Free public hospital treatment of children under 12 years is covered under Welfare, but of course indirect costs still devolve on to the family. The data are expressed as proportional population coverage per province (Fig 9). The pattern is very heterogeneous indeed, with no clear association for example between overall provincial economic status and insurance coverage. Thus Petchaburi Province, with above average GPPpc, has a high Health Card subscription rate whereas Si Sa Ket Province, with a very low GPPpc and greater population has a very low subscription rate. Interpretation of such data is not simple, since many factors are at work: recruitment effort, ability to afford even the low subscription to the Health Card Scheme, willingness/ability to seek medical treatment (critical threshold), etc. In the instance of average malaria case management it may be argued that availability of "free" outpatient treatment might make Health Card cover less attractive. However, in the case of dengue hemorrhagic fever requiring hospitalization this cover could be critical in determining the outcome for an affected child, although Welfare coverage of children under 12 years should offset some costs for dengue hemorrhagic fever since the majority of cases are children. For severe malaria requiring intensive inpatient care the same argument might also be put forward. Perceptions of illness liability may play a role in family assessment of ability to afford Health Card payments, as well as indirect costs of treatment not covered. Dependence on Welfare tends to be greater in some northeastern provinces with low GPPpc and no doubt this is reflected in lower rates of voluntary payment of the registration fee for the Health Card Scheme.

DISCUSSION

This study represents a start in the pursuit of options for using GIS methods to demonstrate possible relationships between disease epidemiology and economic factors of importance in the national and provincial planning process. It makes use of selected databases in a single country. Some of the limitations of the existing databases and their employment in this study are self-evident, *eg* :

• The differing time frame of collection of economic versus disease data severely limits the development of a dynamic framework in a rapidly changing socio-economic and political environment. While overall estimations of national GDP are continually being revised for purposes of approximation of economic growth and planning updates, accurate figures, especially for provinces or smaller geopolitical subdivisions are less readily available. While time series analysis extrapolating from second yearly household survey data might theoretically offer a way of providing more frequent estimates, the advent of the current economic crisis in Thailand and some other countries in eastern Asia serves to underscore the constraints that inevitably would affect the utility of such a predictive approach.

• While other macroeconomic parameters could be added for this type of analysis (*eg* estimates of agricultural industry, manufacturing industry and service industry employment ratios; taxation indices; infrastructure indices), attribution of weighting by province would be more problematic.

• On the other hand, while indices which directly affect health services - physicians, nurses, hospital beds in proportion to the population - have been included for their obvious relevance to seeking/receiving medical care, the ratios given provide no indication as to physical accessibility (transport, communications) or sector (public/private) differentials at province level. In the case of malaria, the distribution of special malaria clinics could add useful information, but perhaps one that would be of greater value at detailed sub-provincial level analysis.

• The disease databases used are simplified: a great deal more information could be included, such as malaria parasite species, categorization of severe or uncomplicated malaria, advent of multi-drug resistant falciparum malaria; dengue serotype epidemiologic pattern, categorization of dengue hemorrhagic fever or uncomplicated dengue fever; mortality rates for both diseases. However, the more limited delineation has been adopted to simplify the comparison with other parameters. The more detailed analyses can readily be added to extend this type of analysis.

• Since both malaria and dengue are vector-borne diseases but are transmitted by different genera/species of mosquito with greatly differing behavior and breeding site distribution, parameters relating to vector ecology and vector control measures employed could potentially add considerably to this type of analysis.

• Similarly available physical environmental information, such as elevation, forest cover, rivers, rainfall, that modulate vector behavior, could usefully be inserted in association with vector data in more detailed analyses, especially at sub-provincial level.

Despite such limitations, interesting comparisons between dengue and malaria have been demonstrated. While over a 6-year period averaged annual malaria patterns did not differ greatly, there were considerable shifts in dengue case distribution, a phenomenon that is well recorded as reflecting geographic population distribution of the different dengue serotypes in relation to herd immunity development and decay over time (Igarashi, 1997). Seasonal malaria variation was also much more limited than that of dengue, presumably reflecting the differing behavior of the vectors and their influence on disease transmission. These differing patterns could well be important in relation to planning equitable, effective and efficient resource distribution (*eg* mosquito control teams) over time if control of these two diseases is to be merged under a single vector-borne disease strategy.

Especially dramatic is the demonstration of the predilection of Thai malaria case distribution for international border regions, especially the Thai-Myanmar border, as against the more diffuse distribution pattern of dengue. This pattern highlights the importance of population movements in the border regions due to commerce, trade, family reunion especially among ethnic minorities inhabiting both sides of border areas, armed conflict, regional political instability and other factors. The distribution of foreign (Cambodian, Lao, Myanmar) malaria cases also reflects these factors but in addition reflects the response of these populations to the accessibility under Thai MOPH policy of free treatment of all malaria cases regardless of nationality. On the other hand this pattern may also highlight the extent of deforestation, hence removal of vector breeding sites. These data focus attention on the necessity of inter-country collaboration in malaria control to improve the situation in the border areas: no one country alone can handle this part of the disease problem. Arguably such collaboration may not be quite so essential for improving dengue control.

The distribution map of GPPpc highlights the well known asymmetric distribution of wealth among provinces and broader regions of Thailand, with the poorest provinces mainly situated in the northeast of the country. Superimposition of disease data on this map does not show any clear, simple correlation between income distribution and disease occurrence. In the case of malaria the dominance of the border predilection would cloud the issue of poverty and disease. Possibly if we mapped the province of origin of the mobile population groups in the border regions we may expect to find that their origins were weighted towards poor northeast provinces, since these have little or no endemic malaria and thus little or no herd immunity, yet it is known that these provinces export workers to other provinces with greater employment opportunities. We do find some anomalies in the distribution of health care resources (physicians, nurses, hospital beds), with aggregation in and around urban/industrial areas and a trend towards inadequate supply in some poorer areas. This may affect patient management capability, but there is no consistent correlation on a province by province basis at the geographic level we have employed. A more sophisticated multiparameter approach including accessibility criteria together with regression analysis might help to unmask important relationships at a subprovincial level.

The employment of Health Card subscription as an indicator of insurance coverage and hence ability to pay might be expected to give a degree of correlation with poverty, but in practice the distribution pattern shows great variation. In the case of dengue hemorrhagic fever this may be important if we examined case fatality rates rather than disease incidence, but in the case of malaria the general availability of "free" diagnosis and treatment as a public good could be expected to cloud the issue somewhat.

It is important to return to the primary purpose for using GIS methods at this macro level of analysis: to provide an entry point for national economic planners and health system planners together to visualize large data sets at a glance, so that common understanding is reached rapidly, enabling detailed further analytical requirements to be decided on the spot in particular circumstances. The present analysis does achieve this objective in certain respects, especially in depicting the greatly differing geographic patterns of two mosquito-borne diseases, dengue and malaria, and doing so against a backdrop of selected resources. One immediate outcome might be contribution to a basis for rationalizing a merger of control programs for the two diseases in terms of material, fiscal and personnel resources in relation to time, season and provincial demands.

A crucial extension would be to apply this approach to regional disease/resource analysis. Thailand has extensive borders with four countries and is close to the southern border provinces (Yunnan, Guangxi) of China (Fig 1). The malaria patterns depicted here serve to underscore the importance of inter-country coordination in communicable disease control programs. This coordination would be greatly facilitated by on-line data flow at frequent intervals, such as is well established in the Chinese disease surveillance network (Chen, 1992). Mapping technology in MapInfo or other formats allows focusing down from the present macro perspective to the local level, so that districts, townships or even villages on either side of a particular border area can be analyzed in relation to changing disease patterns, resource distribution, environmental factors, transport facilities, etc, so to permit detailed collaboration between neighboring country teams. This study demonstrates the potential of applying the HEEDnet (1997) concept to interfacing health, economic, environmental and disease databases for planning resource allocation in relation to cooperative disease control strategies as well as to broader econnmic development.

It is easier for finance ministry administrators without detailed health knowledge to grasp some key points using the GIS approach than using conventional tabular or graphic data. This application of the present methodology combining disease and economic data is of special importance in this context, if extended to more detailed analysis.

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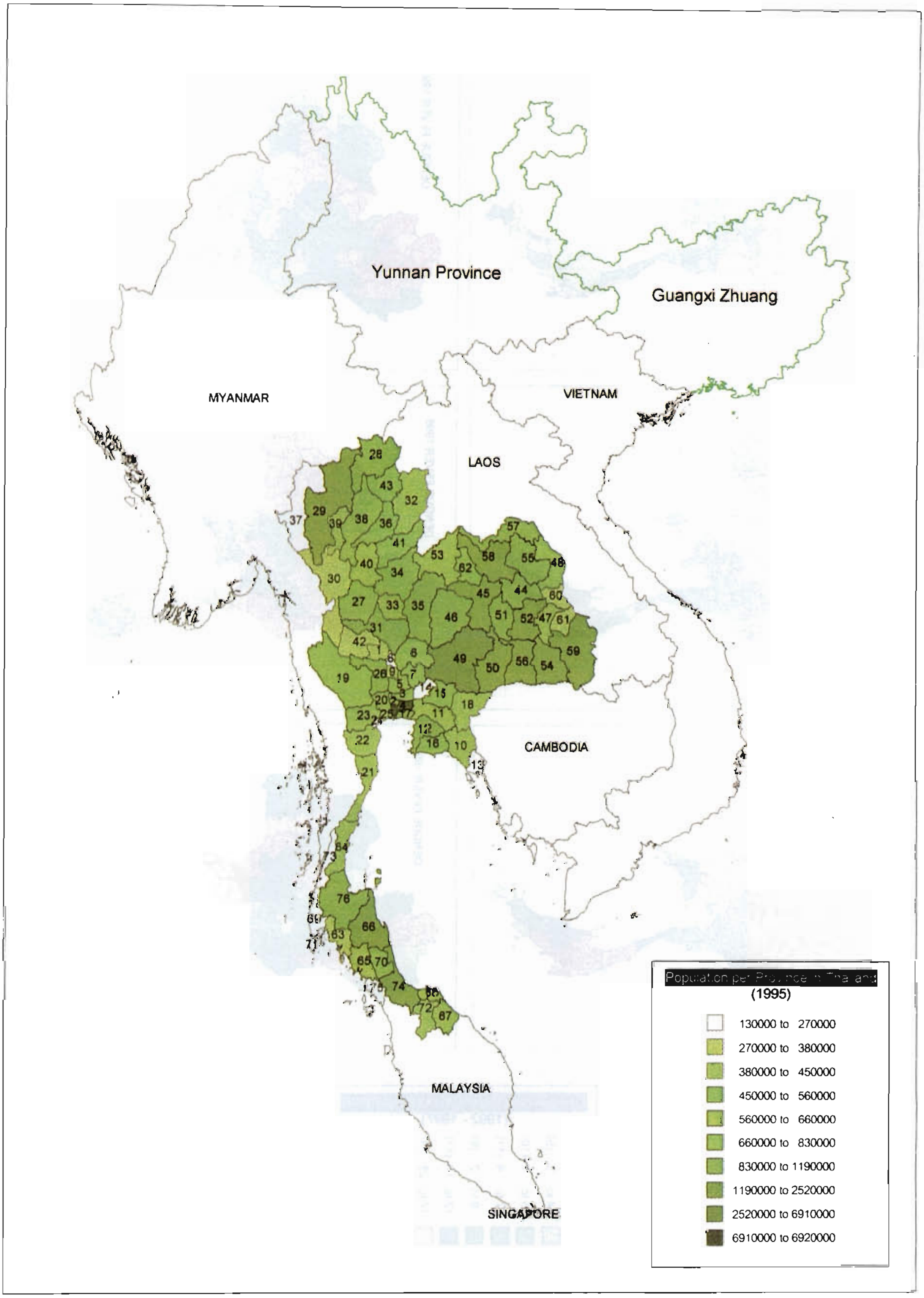


Fig 1–The provinces of Thailand and their population (green) in 1995 depicted in the context of the regional map showing international boundaries. The names of the provinces corresponding to the numbers are listed alphabetically in Table 1.

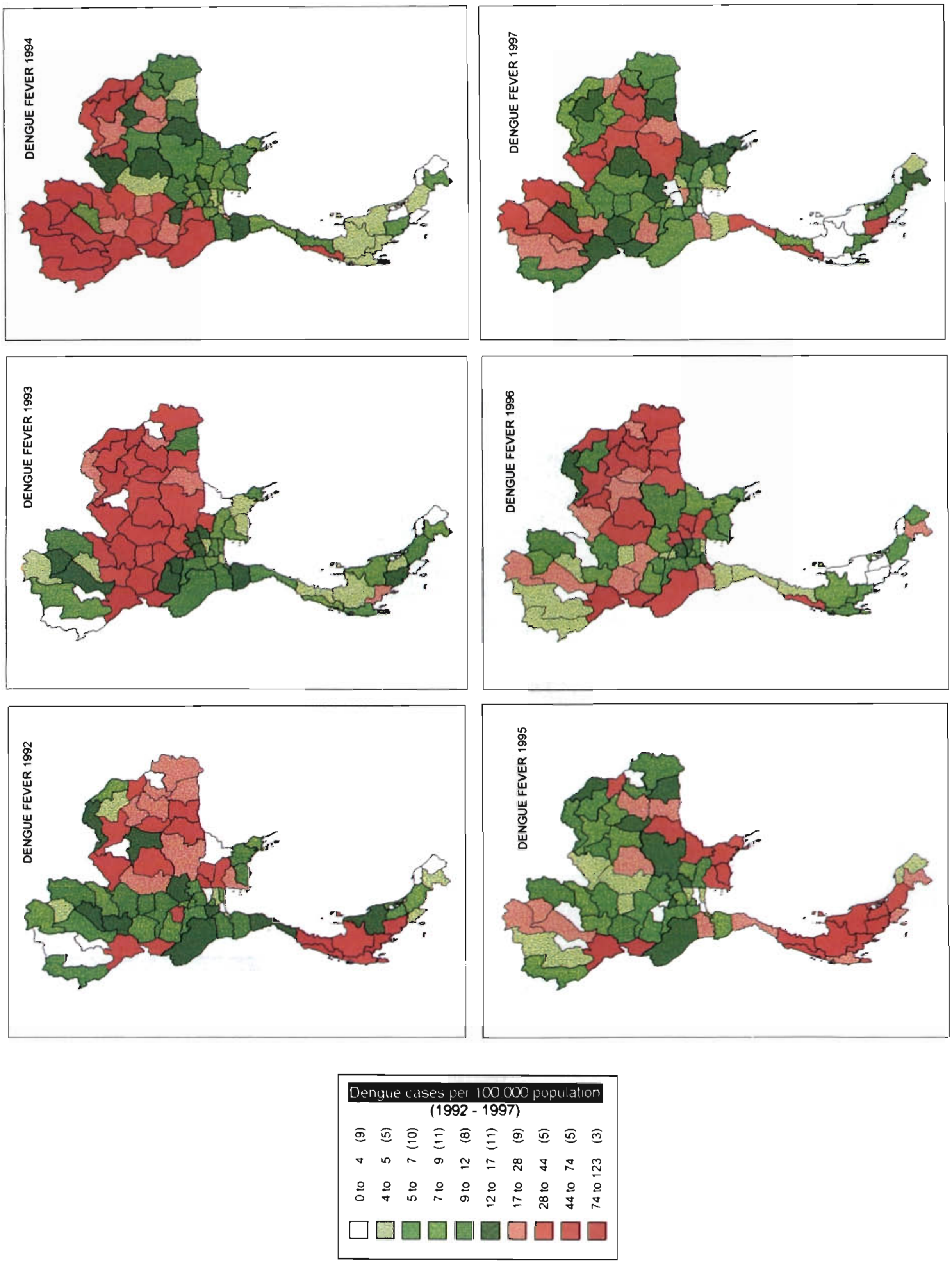


Fig 2–Provincial dengue incidence (cases per 100,000 population) in the 6 years 1992-1997.

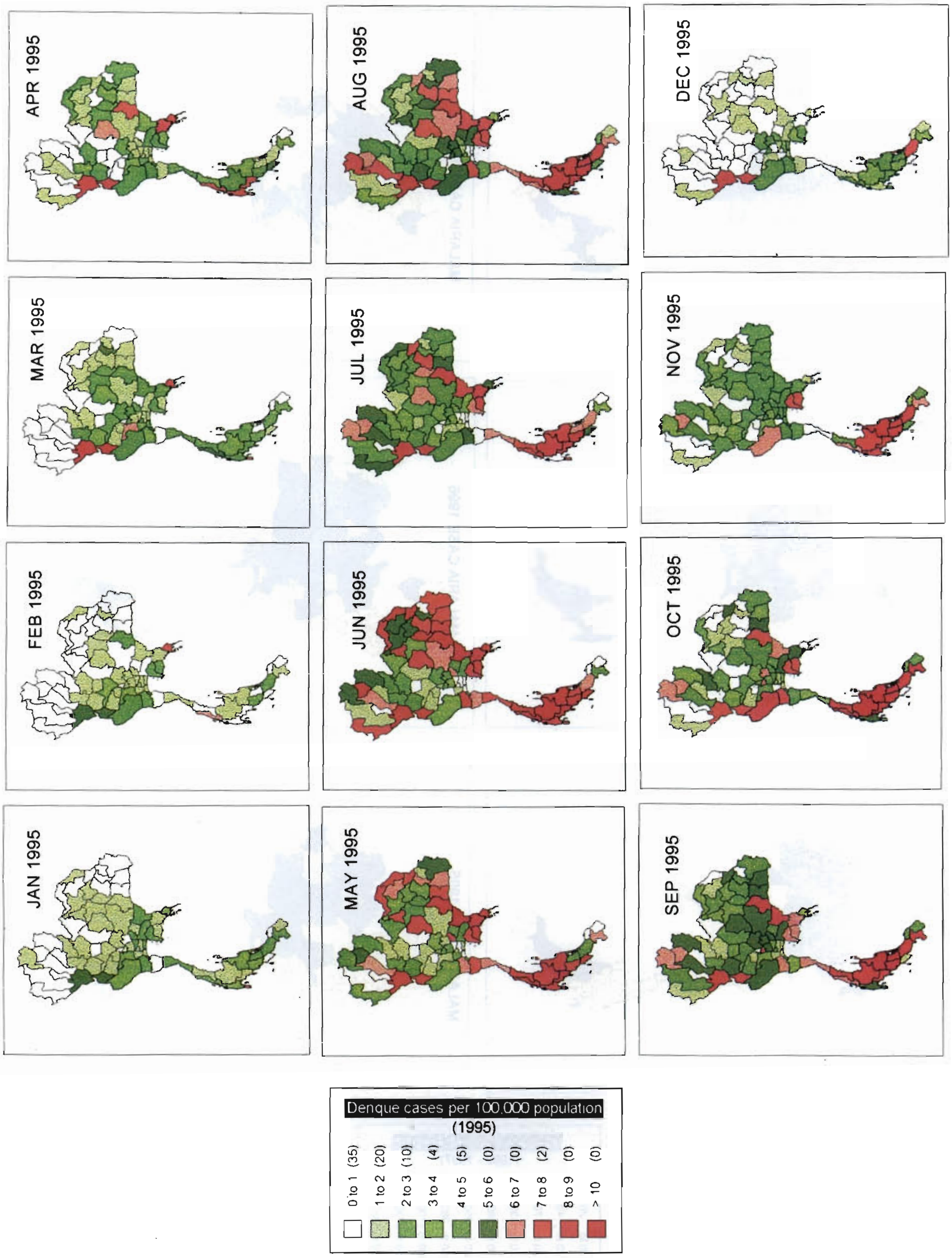


Fig 3–Seasonal variation in dengue incidence (cases per 100,000 population) by province: monthly patterns in 1995.

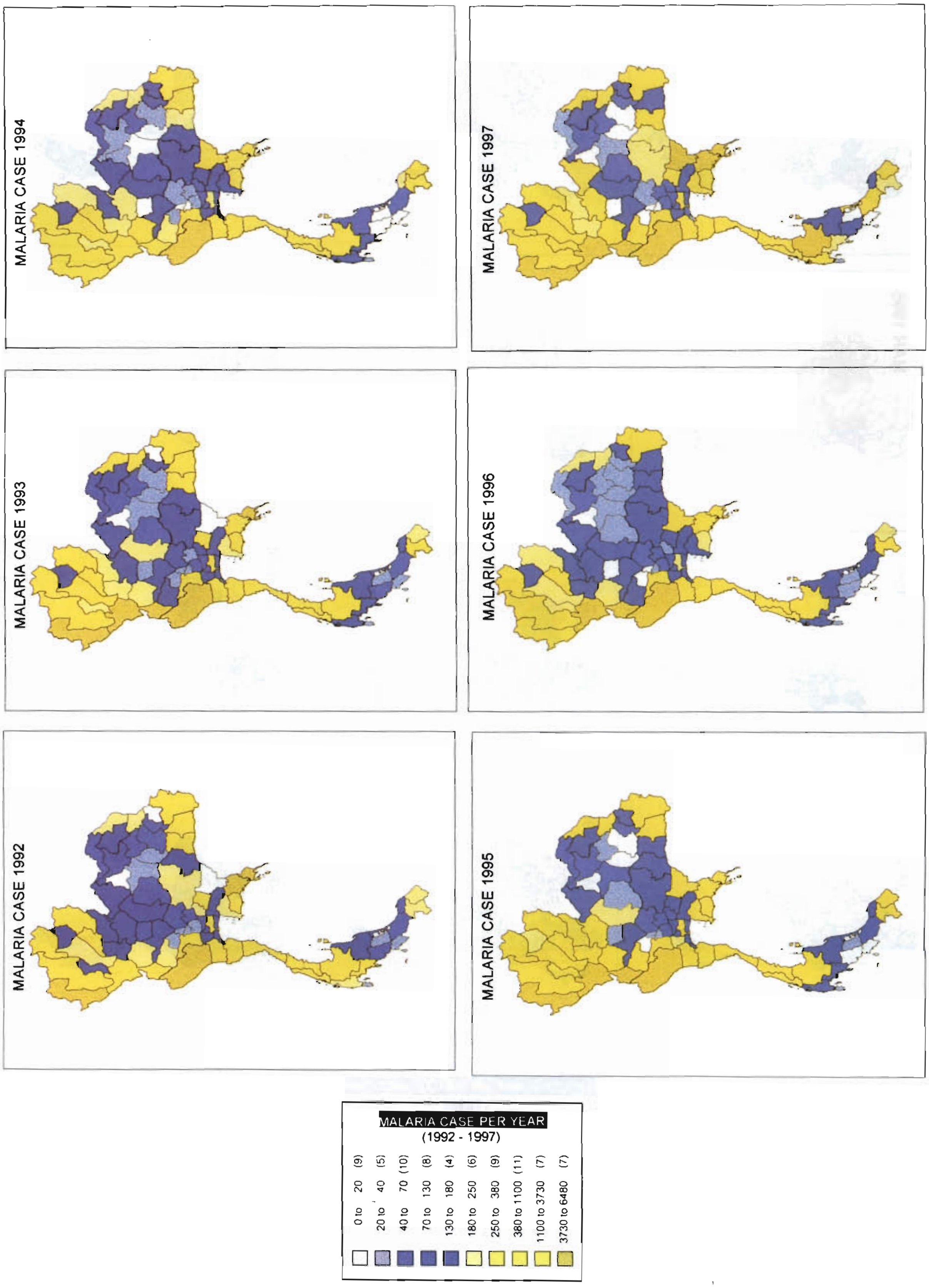


Fig 4–Provincial malaria incidence (cases per 100,000 population) in the 6 years 1992-1997.

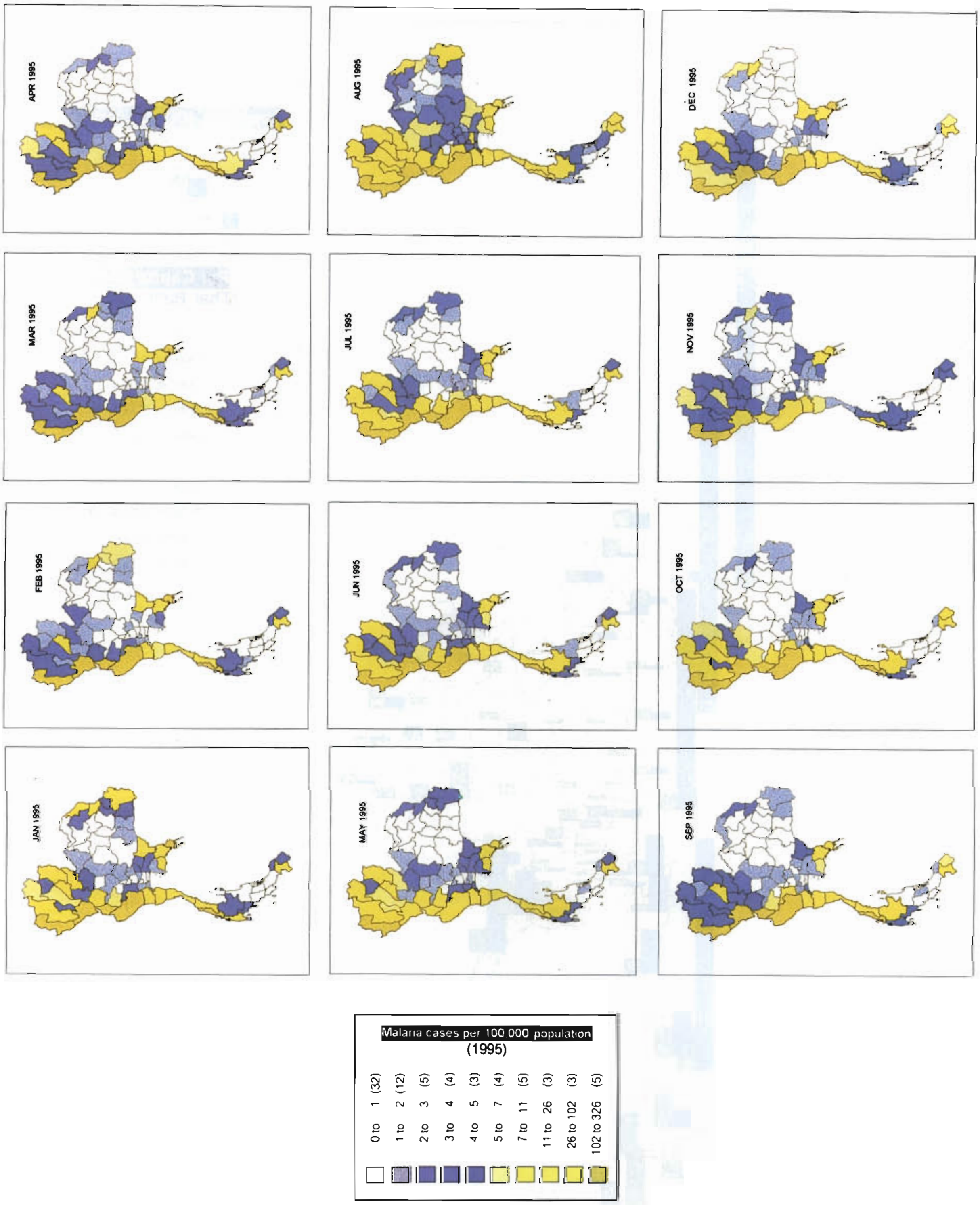


Fig 5–Seasonal variation in malaria incidence (cases per 100,000 population) by province: monthly patterns in 1995.

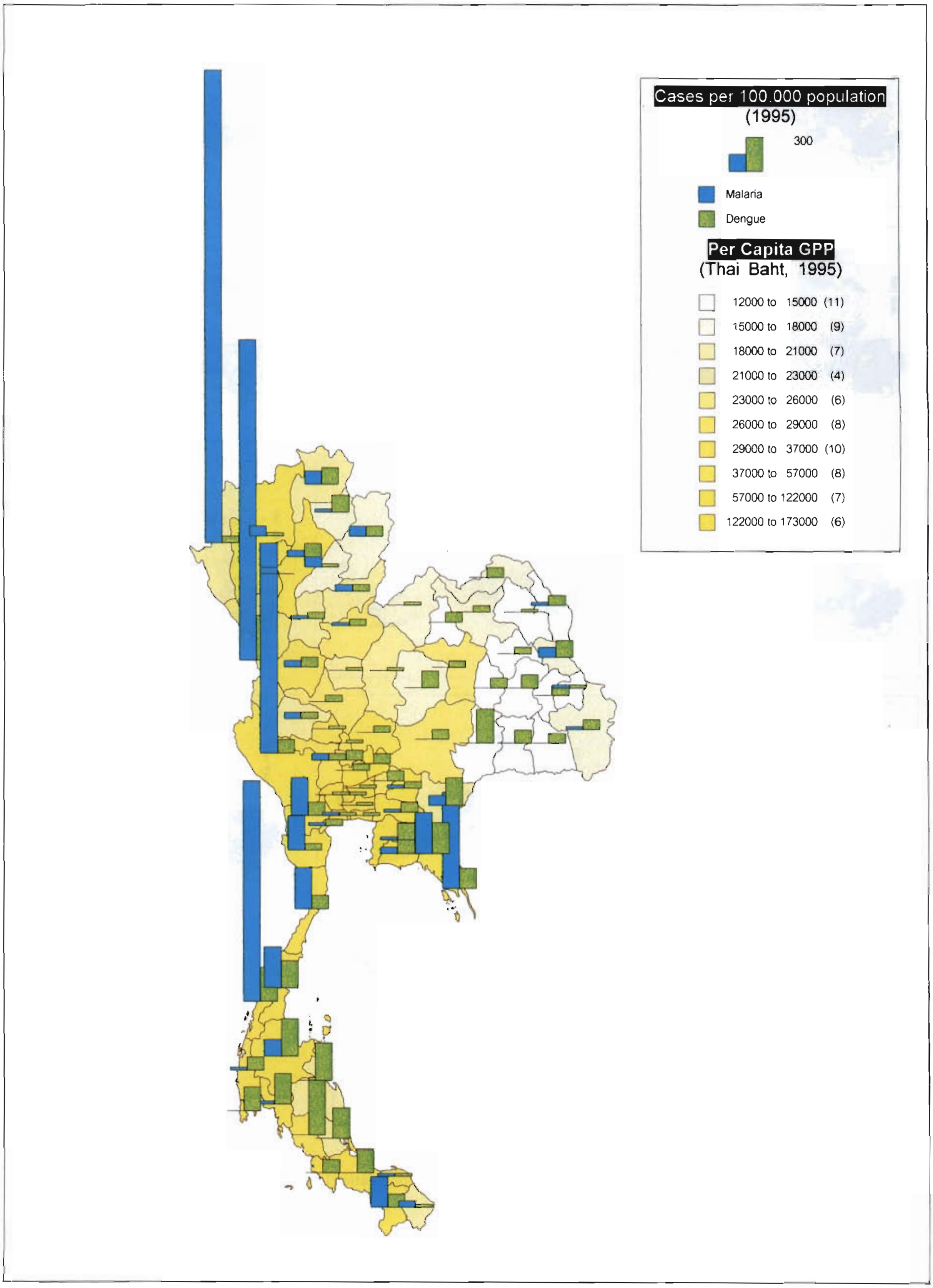
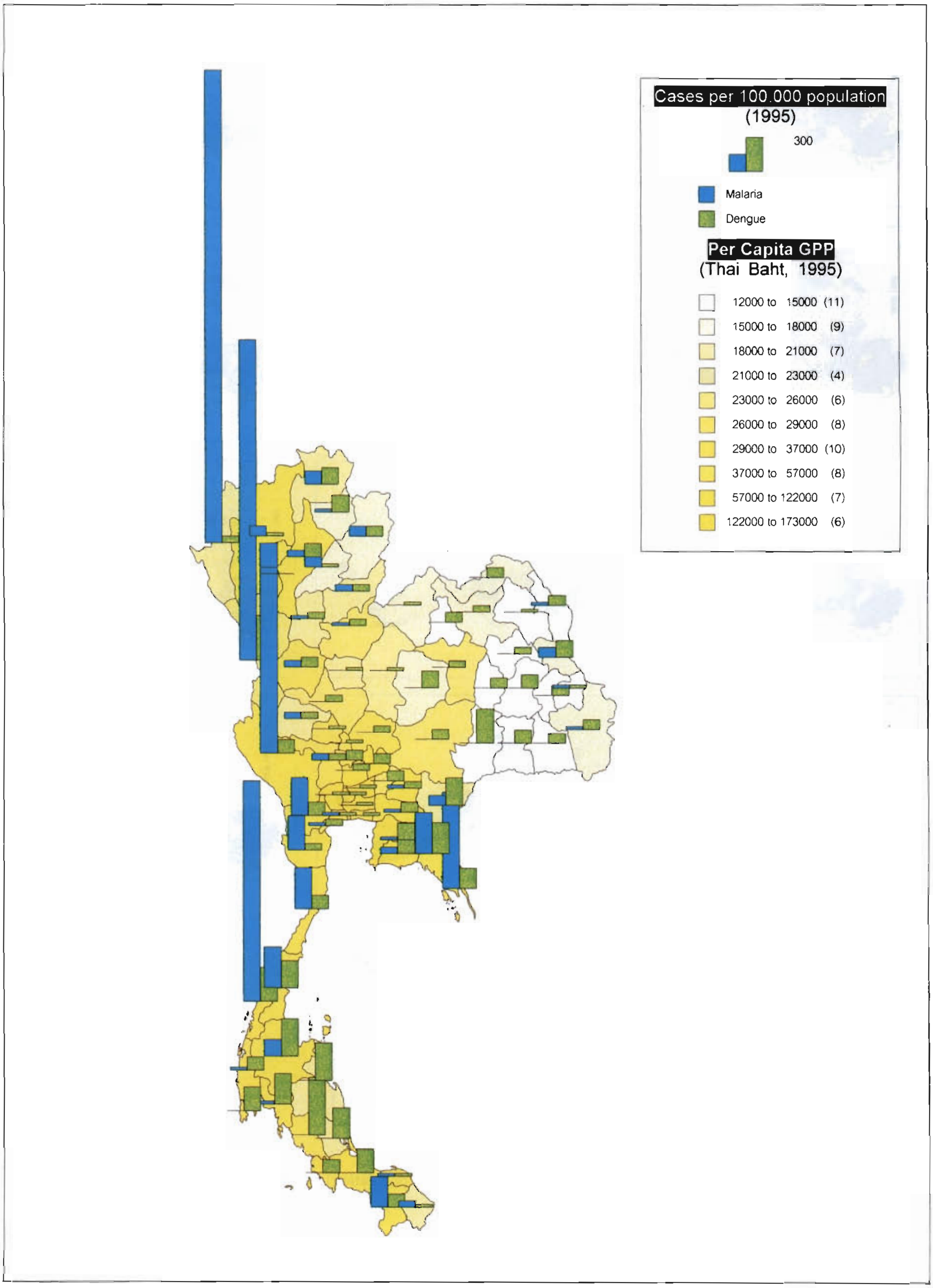


Fig 6– Comparative incidence of malaria and dengue in Thai nationals per province (cases per 100,000 population) overlaid on a map of per capita Gross National Product (GPPpc) for the year 1995.



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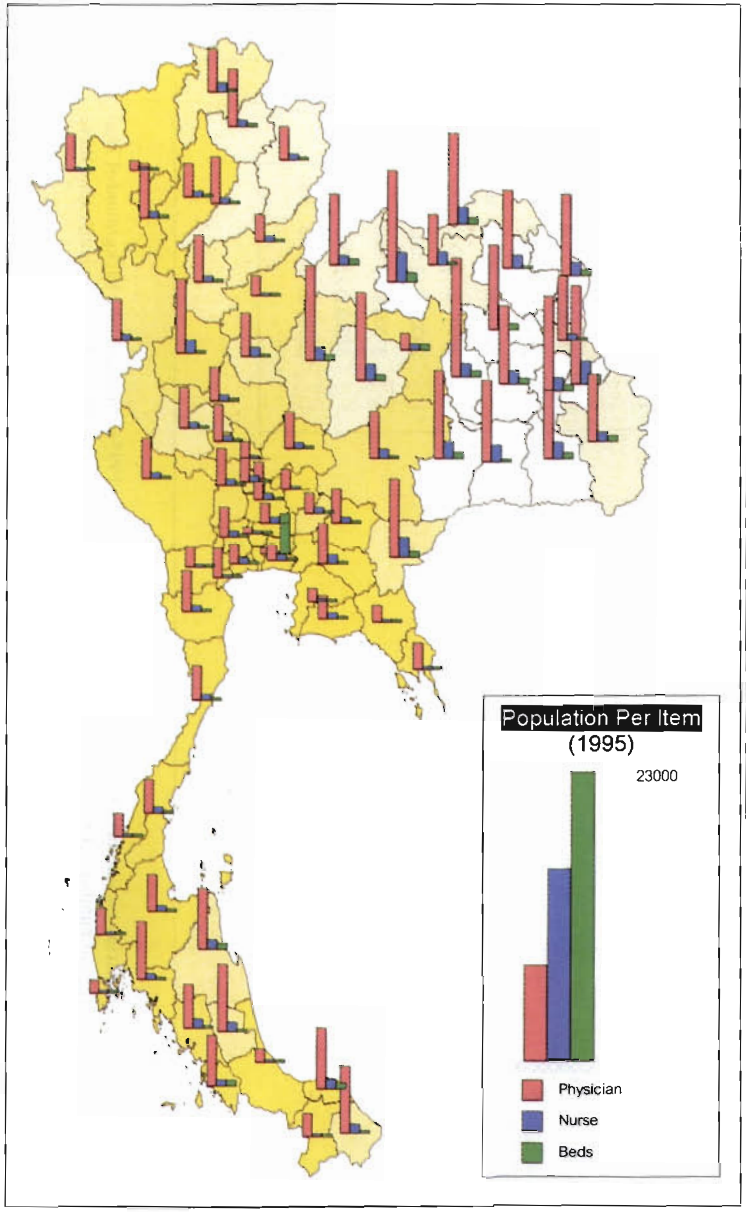


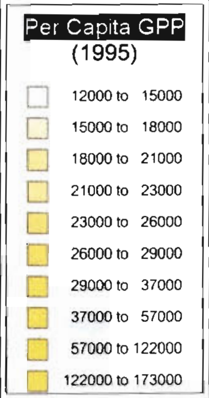


Fig 8–Distribution of health care resources (population per physician, nurse, hospital bed) seen against GPPpc on a provincial basis in 1995.

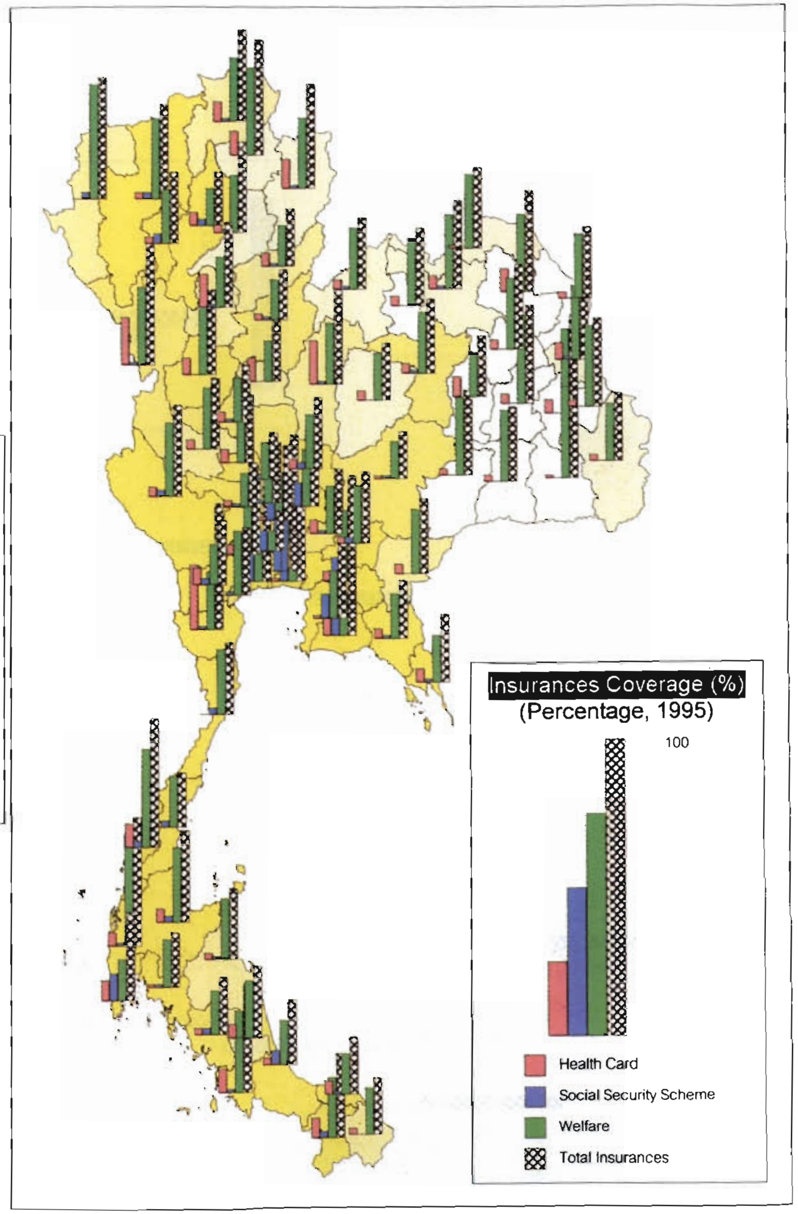


Fig 9–Proportion of population in each province covered by insurance schemes in 1995.

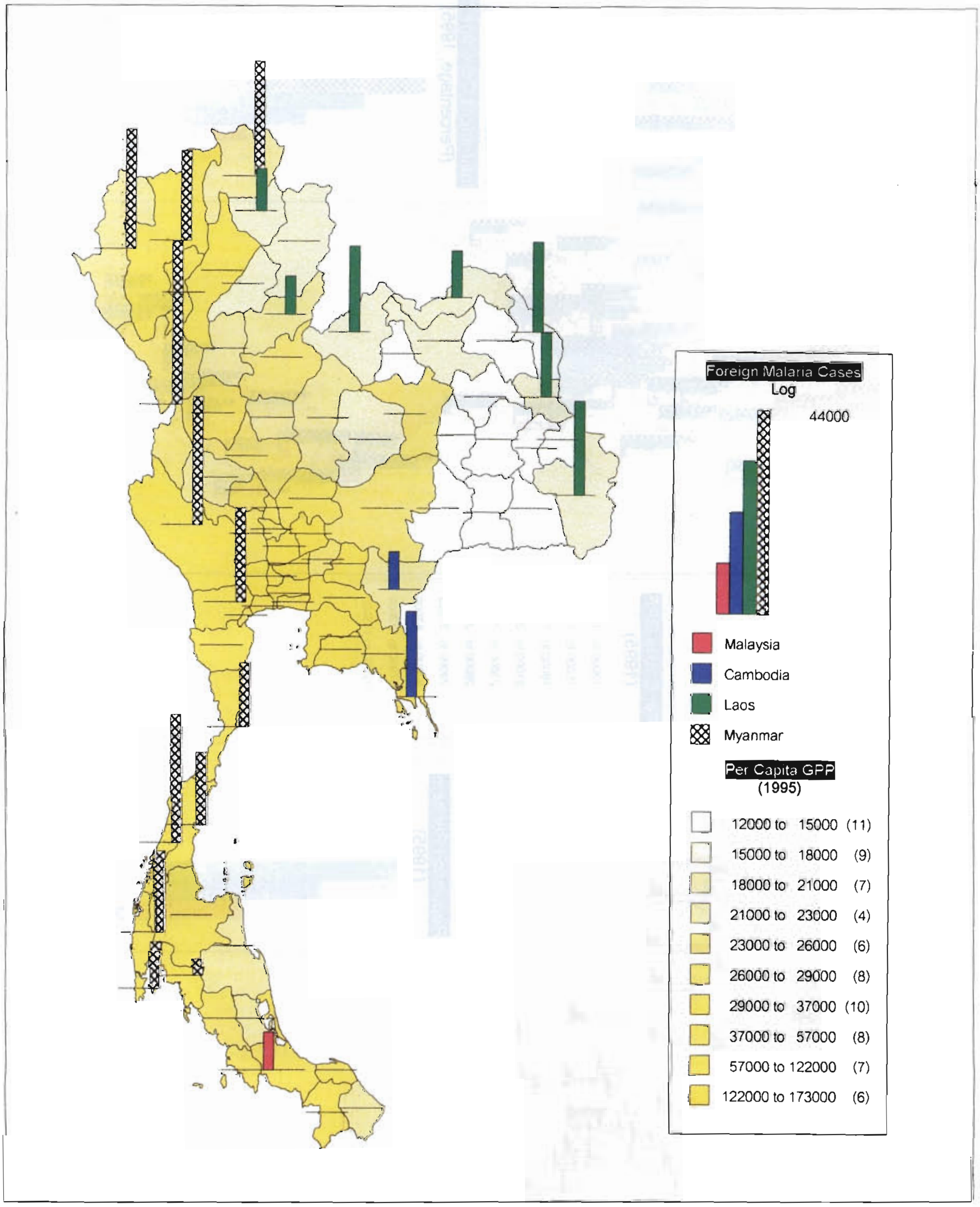
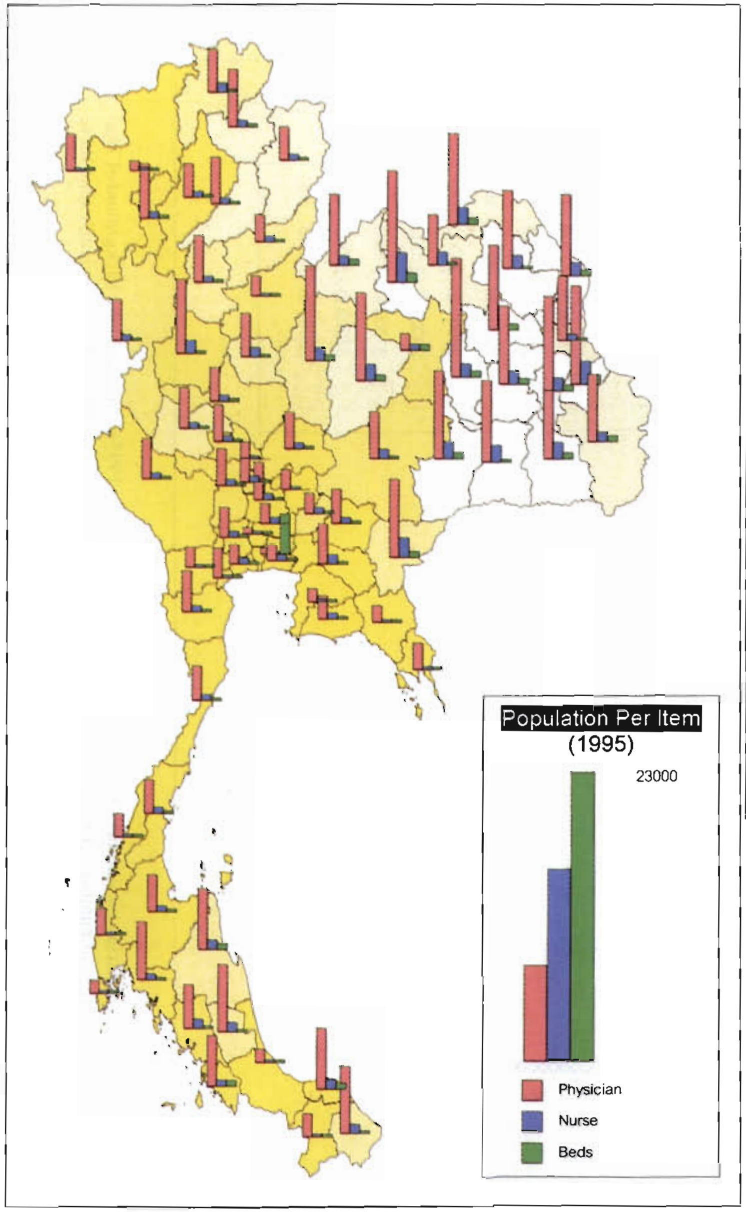
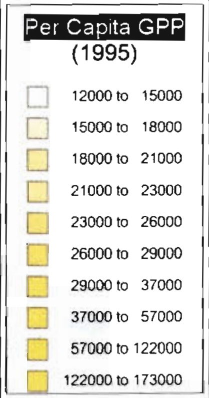


Fig 7– Distribution of malaria case numbers among foreign nationals in the year 1995 seen against the background of Thai GPPpc: since the total numbers of foreign nationals is not known on a provincial basis at any particular time these data cannot be depicted on a per population basis.





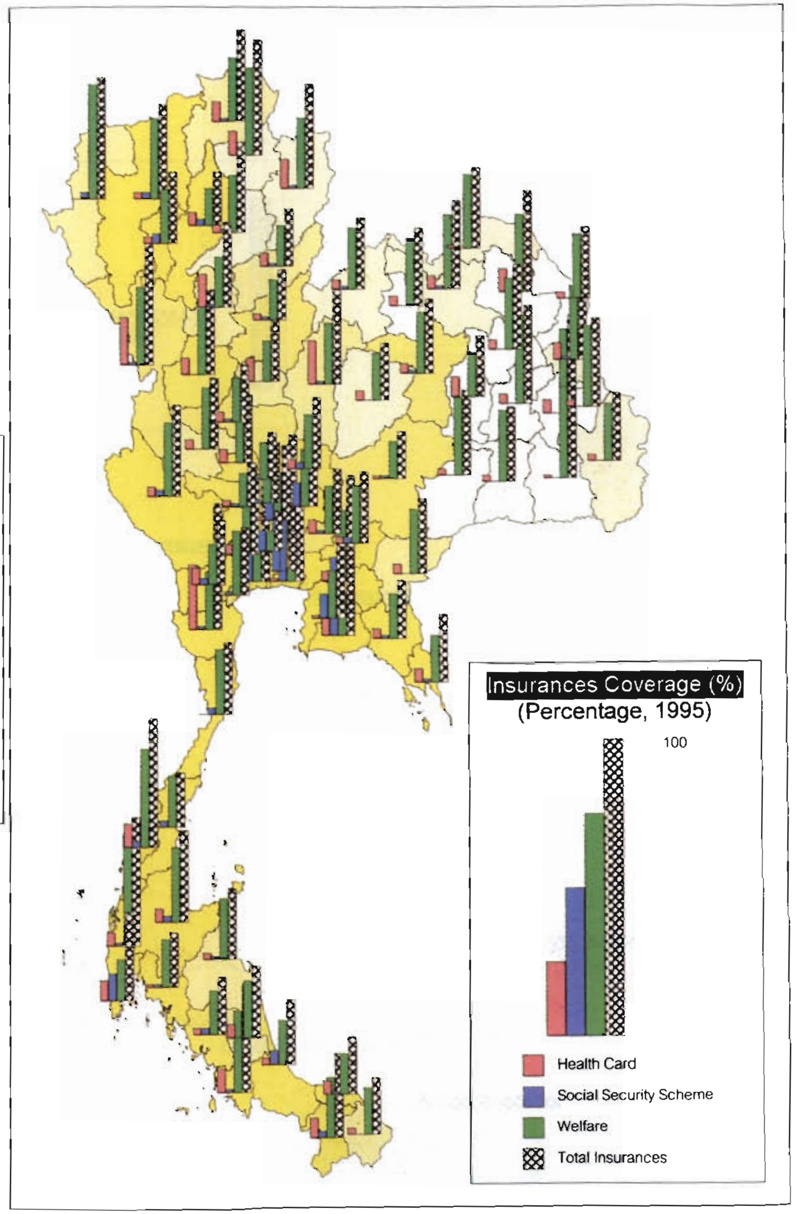


Fig 8–Distribution of health care resources (population per physician, nurse, hospital bed) seen against GPPpc on a provincial basis in 1995.

Fig 9–Proportion of population in each province covered by insurance schemes in 1995.