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Epidemiological analysis of factors influencing rate of progress in *Echinococcus granulosus* control in New Zealand

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SUMMARY

The factors influencing the rate of progress in *Echinococcus granulosus* control in New Zealand were analysed by hydatid control area using stepwise multiple regression techniques. The results indicated that the rate of progress was related positively to initial *E. granulosus* prevalence in dogs and the efficiency with which local authorities implemented national control policy, and negatively to the Maori proportion in the local population and the number of dogs per owner. Problems in analysis of the New Zealand data are discussed and improved methods of monitoring progress in hydatid disease control programmes are described.

INTRODUCTION

The aetiology of echinococcosis and its public health significance in New Zealand were well understood before the end of last century (Macdonald, 1888–9), but the educational and legislative measures introduced to control the disease had little impact. The surgical prevalence rate of human hydatid disease increased steadily to become one of the highest national rates in the world by the 1950s (Burridge, Schwabe & Fraser, 1977), at which time a review of hospital records showed an alarming rise in the incidence of cerebral hydatid disease in children (Begg, Begg & Robinson, 1957). In addition to public health considerations, financial losses from liver condemnations due to hydatid cysts were increasing rapidly and, in 1956, 10% of cattle livers reaching the British market were found to contain deep-seated cysts, throwing suspicion on the whole of New Zealand's meat-inspection procedures (Anon, 1957). It was obvious, therefore, that echinococcosis posed major public health and economic problems to New Zealand and that, if not brought under effective control, it could have drastic consequences for a country largely dependent for its high standard of living and economic stability on an export market in agricultural produce.

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The only country to have controlled hydatid disease successfully on a national scale was Iceland. It was estimated that in the mid-nineteenth century one in every six Icelanders harboured hydatid cysts (Dungal, 1957), whereas today less than one new human case is seen each decade with infection of domestic animals extremely rare (Schwabe, 1969; Beard, 1973). The main credit for the success of the Icelandic control programme was given to an extensive 26-year educational campaign initiated by Krabbe (1864). However, many factors peculiar to Iceland contributed significantly to the result, most notably their small human population, very high literacy rate last century, short killing season for sheep (only 6–7 weeks annually), and reduction of slaughter age for market sheep from 4–5 years to 4–5 months (Schwabe, 1969; Beard, 1973). Consequently, the Iceland experience was somewhat unique and provided only limited guidance to the New Zealand authorities.

A hydatid disease control programme was initiated in New Zealand in 1959 and the implementation of hydatid control measures on a national scale has been described by Laing (1961). Our group has been intermittently associated with that programme on a consulting basis since 1961 and the senior author visited New Zealand in 1975 to carry out an epidemiological analysis of the control effort. A major objective of that study was to determine those factors responsible for the great variation in the rates of reduction of *Echinococcus granulosus* prevalance in dogs in different areas of New Zealand. This paper describes that portion of the study and discusses the significance of the results in relation to the design of future echinococcosis control programmes. Other aspects of the epidemiological analysis have been published elsewhere (Burridge & Schwabe, 1977*a*, *b*; Burridge, Schwabe & Fraser, 1977; Burridge, Schwabe & Pullum, 1977).

MATERIALS AND METHODS

Dog testing

The primary object of hydatid control was to break the life-cycle of *E. granulosus* by denying dogs access to raw offal infected with hydatid cysts. Progress in control was monitored by the regular testing of all dogs for infection with *E. granulosus*, using the taeniafuge arecoline hydrobromide as a diagnostic agent.

New Zealand was divided initially into 85 areas for hydatid control purposes, each administered by a local authority under the overall guidance of the National Hydatids Council. Dogs were tested at central 'dosing strips' by specially trained hydatid control officers (HCOs), each employed by the individual local authority. Dogs were retained on the strips until they were purged. The faecal samples thus collected were sent to the National Hydatids Testing Station, where each sample was examined for tapeworms using the procedure described by Gemmell (1968). The results of faecal examinations allowed estimation of the annual canine prevalence rate of *E. granulosus* by area from the initial testing round of 1959–60 to 1975 (each annual period being for the year ended 31 March).

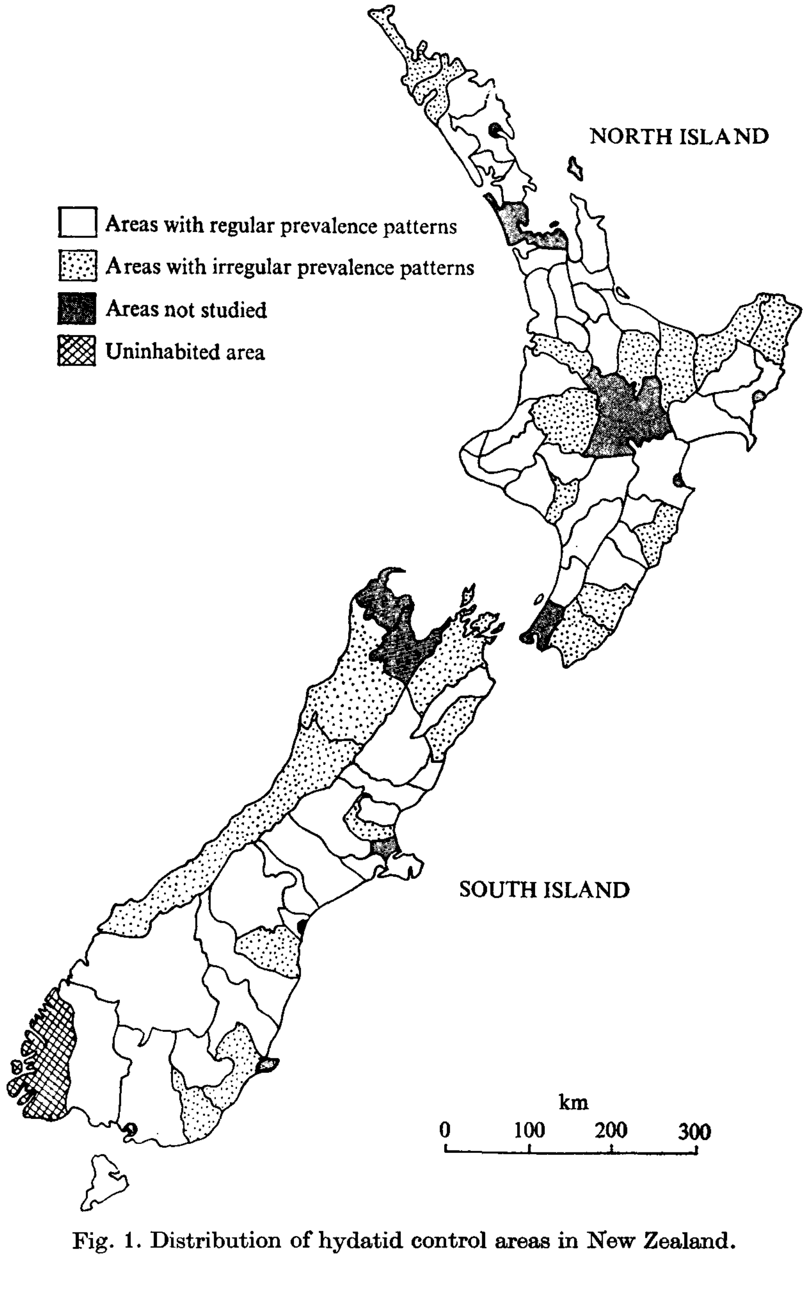

Fig. 1. Distribution of hydatid control areas in New Zealand.

Areas studied

Sixty-nine of the 72 rural areas were considered in this study – 43 in the North Island and 26 in the South Island (Fig. 1). The 3 rural areas excluded were Taupo County in the North Island, owing to the unreliability of its early prevalence data, and Golden Bay and Waimea counties in the South Island, owing to lack of prevalence data after 1966.

The rural areas studied were subdivided into two groups, the 49 areas showing

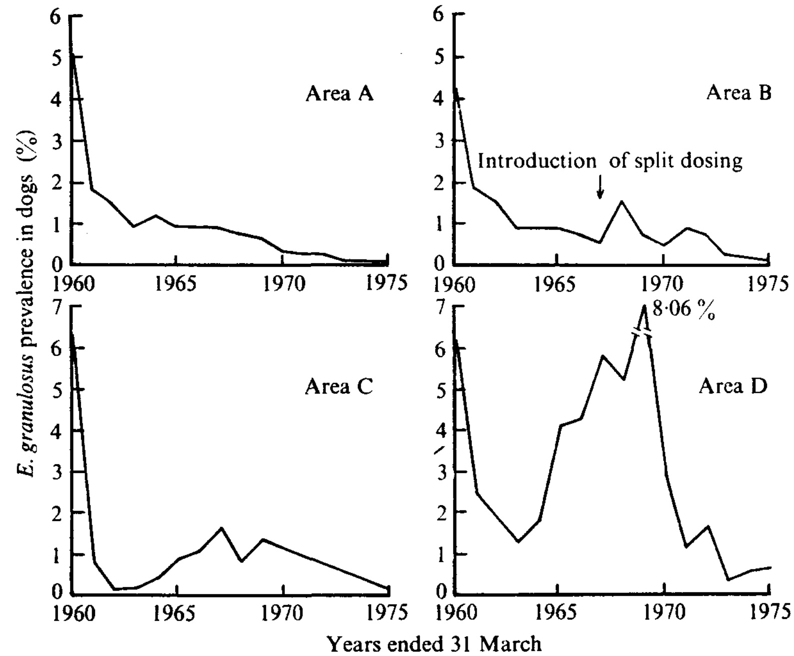

Fig. 2. Temporal patterns in *Echinococcus granulosus* prevalence seen in four hydatid control areas of New Zealand, 1959–75, area A being typical of the 49 areas with regular prevalence patterns and areas B, C and D being examples from the 20 areas with irregular prevalence patterns.

a regular pattern of decline in *E. granulosus* prevalence in dogs and the 20 areas with irregular prevalence patterns (Fig. 1). The reason for this subdivision of control areas was that unusual factors, which had a direct bearing on the accuracy of the prevalence data, were known to have been present in some of the latter areas. Examples of different temporal patterns in *E. granulosus* prevalence are given in Fig. 2, area A being typical of the 49 areas with regular prevalence patterns and areas B, C and D being examples from the 20 areas with irregular prevalence patterns. Area A showed a regular temporal pattern in prevalence, with rapid initial success followed by slow but sustained progress. In area B, 'split dosing' was introduced in 1967 whereby an initial dose of arecoline was followed half an hour later by a second dose, resulting in higher purgation rates and a consequent increase in diagnostic efficiency of arecoline testing. In area C a check test was carried out by the National Hydatids Council in 1966; the results showed that the local HCO was incorrectly testing dogs and sending inadequate faecal purges for diagnosis, leading to estimation of artificially low prevalence rates between 1960 and 1966. The reasons for grossly irregular trends in prevalence, such as that seen in area D, were undetermined.

Variables analysed

The dependent variable measuring the rate of progress in control of *E. granulosus* was defined to be the mean annual percentage reduction in the initial area

Table 1. *Independent variables considered in analysis of rate of progress in* Echinococcus granulosus *control in New Zealand,* 1959–1975

Variable names	Description of variables
Human factors	
Maori	Mean annual % Maoris in human population
Economics	Mean annual % employed rural males earning less than the national median income for that group
Animal husbandry factors	
Sheep Production	% farms with sheep production as major source of income
Area per Farm	Mean grazing area per farm in hectares
Sheep per Farm	Mean annual number of sheep per farm
Sheep Density	Mean annual number of ovine livestock equivalents per hectare of grazing land
Dog factors	
Dogs per Farm	Mean annual number of working dogs per farm
Dogs per Owner	Mean annual number of working dogs per working-dog owner
Factors reflecting sources of dog food	
Initial Prevalence	% *Echinococcus granulosus* prevalence in dogs at beginning of control programme
T. ovis	Mean annual % *Taenia ovis* prevalence in dogs
T. pisiformis	Mean % *Taenia pisiformis* prevalence in dogs for years 1965–6 and 1972–3
Feral Pigs	Relative population density of feral pigs
Feral Goats	Relative population density of feral goats
Control factors	
Rounds per Year	Mean number of annual dog-testing rounds, 1960–8
Dogs per Round	Mean % dogs tested per round, 1960–8
Dogs per HCO	Mean annual number of dogs per hydatid control officer
Years per HCO	Mean number of years each hydatid control officer employed
HCO Quality	Mean quality of hydatid control officers

prevalence of *E. granulosus* in dogs between the first testing round in 1959–60 and the year ended 31 March 1975.

The independent variables considered for analysis are described in Table 1, and each was computed for the period 1960–75 except where otherwise stated. They were chosen primarily for their possible effects on the life-cycle of *E. granulosus* (animal husbandry and dog factors), on dog-feeding patterns (human factors and prevalence variables), and on the availability of alternative sources of dog food (feral animals). In addition, variables were constructed to reflect area differences in implementation of national control policy (control factors).

The Sheep Density variable was estimated on the basis of the relative feed requirements of cattle and sheep, assuming that one unit of grazing land could support alternatively 1 cow/steer or 8 ewes (i.e. 1 cow or steer = 8 livestock equivalents = 8 ewes). Annual data on *Taenia pisiformis* prevalence in dogs were available by area only for the years 1965–6 and 1972–3. The relative population densities of feral pigs and goats were ranked from zero for absent to 7 for heaviest density, using the data of Wodzicki (1950) and 1968 data from the New Zealand Forest Service on the distribution of those feral species.

The logic behind the choice of control programme variables was as follows:

(a) Rounds per Year – reflected the efficiency with which each local authority tested their dogs since national control policy required at least 3 testing rounds a year (Laing, 1961);

(b) Dogs per Round – measured the extent of coverage of the local dog population by the control programme;

(c) Dogs per HCO – measured the number of dogs to be tested by each HCO and thus indirectly estimated the amount of time available for educational extension work;

(d) Years per HCO – indicated the extent of turnover of control staff in each area;

(e) HCO Quality – estimated the overall relative quality of HCOs by area.

The last variable was computed as follows. Each HCO was ranked from 4 for excellent to zero for very poor on each of five criteria: integrity, field efficiency on dog-testing strips, involvement in community education, record keeping and filing reports, and the quality of faecal samples sent for diagnosis. The scoring was done by the Chief Veterinary Officer and the seven Field Advisory Officers of the National Hydatids Council. The HCO Quality variable was calculated from these scores, the mean score of each HCO being weighted for length of employment.

Method of multivariate analysis

The stepwise multiple regression subprogramme of the Statistical Package for the Social Sciences (Nie *et al.* 1975) was used to examine the factors influencing the rate of progress in *E. granulosus* control. The computer output gave the order of entry of independent variables into the regression equation, together with the coefficients of multiple determination R^2, which estimated the proportion of the total variation in the dependent variable explained by the regression equation at each successive step. This output was used to attempt to select a subset of the available variables that would give the optimal prediction equation for the rate of progress in control of *E. granulosus*.

The subprogramme gave the standardized regression coefficient for each independent variable entered into the final equation. That coefficient measured the magnitude and direction of the direct effect of an independent variable since it was computed with all other independent variables held constant. Therefore, a change of one standard deviation in a given independent variable, when all other independent variables in the regression equation were held constant, altered the dependent variable by an amount equal to the product of its own standard deviation and the standardized regression coefficient.

The regression analysis also gave the mean and standard deviation of each variable and a correlation matrix showing the zero-order correlation coefficients for every pair of variables.

The stepwise regression analysis was carried out initially on data from the 49 areas showing a regular pattern of decline in *E. granulosus* prevalence, and was then repeated using data from all 69 rural areas studied.

Table 2. *Correlation matrix showing zero-order correlation coefficients between* Echinococcus granulosus *control programme variables for New Zealand,* 1959–1975

	Rounds per Year	Dogs per Round	Dogs per HCO	Years per HCO	HCO Quality
Rounds per Year	1·000*	−0·181	−0·030	−0·114	0·093
	1·000	−0·166	−0·022	−0·088	0·135
Dogs per Round	−0·181	1·000	−0·139	0·020	0·096
	−0·166	1·000	−0·083	0·058	−0·025
Dogs per HCO	−0·030	−0·139	1·000	−0·083	−0·179
	−0·022	−0·083	1·000	−0·080	−0·182
Years per HCO	*−0·114*	*0·020*	*−0·083*	*1·000*	*−0·165*
	−0·088	0·058	−0·080	1·000	*0·010*
HCO Quality	*0·093*	*0·096*	*−0·179*	*−0·165*	*1·000*
	0·135	−0·025	−0·182	0·010	1·000

* Coefficients for 49 areas with regular patterns of progress above coefficients for all 69 rural areas studied.

Table 3. *Summary of results of stepwise multiple regression analyses run to determine variables influencing rate of progress in* Echinococcus granulosus *control in New Zealand,* 1959–1975

Areas with regular patterns of progress only		All areas	
Variables entered*	Cumulative R^2	Variables entered*	Cumulative R^2
Maori	0·229	Maori	0·215
Rounds per Year	0·319	Rounds per Year	0·304
Dogs per Owner	0·387	Dogs per Owner	0·340
Initial Prevalence	0·457	Initial Prevalence	0·426
T. pisiformis	0·508	Feral Pigs	0·449
Area per Farm	0·587	Years per HCO	0·470
HCO Quality	0·602	HCO Quality	0·487
Sheep per Farm	0·612	Area per Farm	0·501
T. ovis	0·630	*T. pisiformis*	0·522
Dogs per Farm	0·649	—	—
All variables	0·670	All variables	0·558

* Only variables adding 0·01 or more to R^2 included; see Table 1 for definitions of variables.

RESULTS

A visual comparison of the means of independent variables between areas with regular and irregular patterns of decline in *E. granulosus* prevalence showed that the major differences between the two areas involved five variables. On average, initial *E. granulosus* prevalence, proportion of Maoris and feral pig density were higher, and mean area per farm and *T. pisiformis* prevalence were lower, in areas with irregular patterns of progress.

A portion of the correlation matrix is given in Table 2, showing the zero-order correlation coefficients between the control programme variables. There was very

Table 4. *Standardized regression coefficients in stepwise multiple regression analyses run to determine variables influencing rate of progress in* Echinococcus granulosus *control in New Zealand*, 1959–1975.

Independent variables*	Standardized regression coefficients: Areas with regular patterns of progress only	All areas
Human factors		
Maori	−0·60	−0·33
Economics	+0·09	+0·06
Animal husbandry factors		
Sheep Production	−0·18	+0·25
Area per Farm	+0·38	+0·46
Sheep per Farm	−0·68	−0·39
Sheep Density	−0·15	+0·25
Dog factors		
Dogs per Farm	+0·60	+0·06
Dogs per Owner	−1·01	−0·60
Factors reflecting sources of dog food		
Initial Prevalence	+0·54	+0·40
T. ovis	+0·25	+0·20
T. pisiformis	−0·51	−0·25
Feral Pigs	+0·09	−0·15
Feral Goats	−0·10	−0·03
Control factors		
Rounds per Year	+0·34	+0·40
Dogs per Round	+0·09	+0·08
Dogs per HCO	−0·01	+0·12
Years per HCO	−0·03	+0·19
HCO Quality	+0·07	+0·16

* See Table 1 for definitions of variables.

little linear relationship between any of those variables, indicating that each variable measured essentially a different 'dimension'.

The results of the stepwise regression analyses are summarized in Tables 3–4. The order of entry of the first four variables into the regression equation was identical with both analyses (Table 3), with each variable contributing a similar proportion to the cumulative R^2 of each analysis. The variables Maori, Rounds per Year, Dogs per Owner, and Initial Prevalence would, therefore, be important predictors of the rate of progress in *E. granulosus* control, but with only those four variables in the prediction equation, less than half the total variation in the dependent variable was explained.

The standardized regression coefficients for the analyses are shown in Table 4. The variables with the greatest direct effects on the rate of progress in *E. granulosus* control were the Maori proportion of the population, farming factors (area per farm, numbers of sheep per farm, and numbers of dogs per farm and per owner), *T. pisiformis* prevalence (reflecting exposure of dogs to rabbit offal), initial

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E. granulosus prevalence, and the number of dog-testing rounds completed annually. The latter variable was the only control factor having a major direct effect on the rate of progress, and it was the variable chosen to measure the efficiency with which each area tested dogs to monitor progress in the control programme.

DISCUSSION

There is an increased realization that the failures of many disease control programmes in the past were due, in part, to an incomplete understanding of the complex relationships between biological, cultural, socio-economic, agricultural and environmental factors that determine patterns of transmission of many parasites. It is of great importance, therefore, to gain as much knowledge as possible about the epidemiology of diseases from existing control programmes so that future control strategies can be formulated on a rational basis. This can be done by the application of multivariate statistical techniques to data collected during a control programme with the object of identifying important relationships between variables that influence the rate of progress in disease control. Such a study is reported in this paper and it is hoped that the results from the New Zealand programme will be of value to other regions of the world where hydatid disease caused by *E. granulosus* remains an important public health problem, most notably the Mediterranean littoral, southern and central U.S.S.R., and southern South America (Schantz & Schwabe, 1969). Since the inception of the New Zealand programme, two other regions have initiated hydatid disease control campaigns, Tasmania (Meldrum & McConnell, 1968) and Cyprus (Polydorou, 1971), and one, the department of Flores in Uruguay, has started a pilot project (Purriel, Schantz, Beovide & Mendoza, 1973).

The results of this study indicated that four factors had a major influence on the rate of progress in *E. granulosus* control in New Zealand. They were an ethnic factor involving the Maori people, the number of dogs per owner, the prevalence of *E. granulosus* in dogs at the beginning of the control programme, and the number of dog-testing rounds completed annually. In addition, a concurrent study showed that the major pre-control determinants of *E. granulosus* prevalence in New Zealand dogs included the Maori variable and sheep husbandry factors (Burridge, Schwabe & Pullum, 1977).

The high prevalence of *E. granulosus* detected in dogs owned by Maoris was found to be due to a combination of poor dog control, cultural factors, and a complex system of land tenure that retarded the development of Maori farming methods (Burridge & Schwabe, 1977*a*). That situation had two important consequences: it placed Maoris at a high risk of acquiring hydatid disease and it impeded overall progress in *E. granulosus* control in areas containing a high proportion of Maoris. These findings emphasize the importance of cultural factors in the control of hydatid disease. Several other ethnic groups have been identified which appear to be at an unusually high risk of infection with *E. granulosus* owing to special cultural features; examples are the Turkana tribe of Kenya (Schwabe, 1969; Nelson, 1972) and the Basques of California (Araujo, Schwabe, Sawyer &

Davis, 1975). To control hydatid disease, it is necessary to change human attitudes and behavioural patterns, particularly with regard to dog feeding, that have often become ingrained over generations. It is well understood that that can only be achieved through motivation of target groups, the dog-owning and farming communities, to participate voluntarily in control efforts before implementation of compulsory control measures, and that such motivation is best accomplished by an intensive educational campaign (Begg, 1961; Beard, 1969). In addition, it is also necessary to modify special cultural adaptations peculiar to particular ethnic groups that favour continuation of the *E. granulosus* transmission cycle. The latter aspect received insufficient attention in New Zealand to the detriment of the overall rate of progress in hydatid disease control.

The initial prevalence of *E. granulosus* in dogs, measured during the first dog-testing round in 1959–60, was positively related to the rate of progress in control. By 1958, over 800 voluntary control schemes were in operation throughout New Zealand which had had differing degrees of success in reducing the canine prevalence of *E. granulosus* by the time of inception of the national control programme (Gemmell, 1961). It is probable that the increased rate of progress seen in areas with high initial prevalences was due, in part, to an immediate success in gaining the co-operation of the majority of the dog-owning community. However, it is also possible that part of the rapid decline in prevalence in those areas was unrelated to the control programme and was simply the result of 'regression towards the mean'. In contrast, many areas with lower initial prevalences had probably experienced early success in control during the voluntary schemes and continued progress after 1959 was slower owing to the extra efforts required to overcome uncooperative dog owners.

Only one of the five control variables was found to have a major effect on the rate of progress in reduction of *E. granulosus* prevalence. That variable was the one chosen to reflect the efficiency of the local authority in implementing national control policy. The only measure of the relative quality of the 430 HCOs employed by the 87 local authorities during the first 16 years of the national control programme was a subjective evaluation made by staff of the National Hydatids Council. In the absence of objective criteria, no conclusion could be reached regarding the influence of the quality and performance of local control staff on progress in hydatid control.

Interpretation of the results of this study has been conservative because of recognized measurement errors in the dependent variable and the inaccuracies evident in the data from some areas (see Fig. 2). Progress in control was monitored using the taeniafuge arecoline hydrobromide as a diagnostic agent, the best available method of diagnosis of canine echinococcosis although one of relatively poor sensitivity. Under field conditions in New Zealand and Australia, arecoline hydrobromide failed to purge more than a fifth of the dogs dosed with 3·5 mg/kg body weight (Gemmell, 1958, 1968; Jackson & Arundel, 1971; Gregory, 1973). In addition, Jackson & Arundel (1971) found that purgation rates varied from 64·7 % to 86·2 % in the nine areas of Victoria that they surveyed. It is clear, therefore, that canine prevalence rates should be calculated on the basis of dogs successfully purged when comparing rates from different areas. No accurate data on purgation rates were collected during the New Zealand control programme and thus all prevalence figures were estimated as a percentage of dogs tested, giving artificially low infection rates.

Another factor that reduced the accuracy of the prevalence data was the introduction of alternative methods of administration of arecoline hydrobromide. Forbes (1961) demonstrated that, in dogs failing to respond to oral dosing, the purgative efficiency of arecoline was improved by the subsequent use of arecoline enemata. As a consequence, enemata were introduced as an additional diagnostic tool early in the control programme. However, as Gemmell (1968) pointed out, the increase in purgation rate was due purely to the enema stimulating evacuation of the large intestine and, in fact, there was no material improvement in the diagnostic efficiency of arecoline hydrobromide. It was found that there was a tendency, especially for overworked or ill-informed HCOs, to use enemata to obtain a quick purge, reducing the normal diagnostic efficiency of oral arecoline. As a result, their use in the control programme was discouraged, but not prohibited. Also, the introduction of split dosing or redosing with arecoline to some areas increased the diagnostic efficiency of the drug. Without knowledge of where or when those dosing routines were employed, it was impossible to establish their effect on the rate of progress in hydatid control.

The unit of concern in *E. granulosus* control should be the dog owner (or farm) rather than the dog. Infection in a single dog is evidence that the owner is permitting his dogs access to raw offal and, therefore, all his dogs must be considered potentially infected with *E. granulosus*. For this reason, progress in control is best assessed by relating infections to dog owners and expressing prevalence data in terms of the proportion of owners with infected dogs, as was done in Tasmania (Bramble, 1974). An added advantage of such a monitoring system is that it allows on-going analysis of the characteristics of uncooperative owners whereby educational methods can be modified to further improve the efficiency of the control programme. If a similar system had been used in New Zealand, it would have become quickly apparent that changes were required in educational and extension policy towards Maori dog owners.

It is also important to monitor *E. granulosus* morbidity rates in intermediate hosts. Changes in incidence were carefully recorded in people in New Zealand (Foster, 1958; Burridge, Schwabe & Fraser, 1977), but only rudimentary surveys were carried out in livestock. Sheep provide an important indicator of progress in hydatid control, especially when canine prevalence has been reduced to a low level. However, monitoring progress through slaughtered sheep requires an efficient trace-back system so that the farm of origin of infected animals can be determined. Tasmania has devised a successful trace-back system and it has proved a valuable method of identifying problem properties (Bramble, 1975). It has also permitted introduction of quarantine measures in Tasmania, restricting the movement of sheep from heavily infected properties to sale for immediate slaughter and thus preventing their dissemination throughout the state.

It is of the utmost importance for disease control programmes to show convincing evidence of progress if they are to maintain public support (World Health Organization, 1968). In this regard, the conclusions of the present study provide a basis for improvements in the design of a system for monitoring progress in future hydatid disease control programmes. Prevalence and incidence data must be collected and presented in a uniform manner, allowing accurate comparison of progress by areas as the campaign proceeds. That can only be achieved if all aspects of the control programme are under the authority of one single body; such a situation was recommended in New Zealand when it was suggested that all local authorities be relieved of their hydatid control obligations (Anon, 1967), but the recommendation was not implemented. Morbidity data should be expressed in terms of the proportion of owners with infected dogs, and monitoring of progress through slaughtered sheep should be instituted using a livestock trace-back system. Finally, cultural factors favouring transmission of *E. granulosus* should be considered, with appropriate modifications made to the design of the control programme to overcome their effects.

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