

Original Article

The seroprevalence and spatial distribution of liver fluke infection in a sample of West Coast and Canterbury dairy herds

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ABSTRACT

The West Coast region of the South Island of New Zealand is recognised as having a high prevalence of liver fluke infection, however, few studies have tested this assumption. This study aimed to estimate the seroprevalence and spatial distribution of liver fluke infection in most West Coast and some Canterbury dairy herds using bulk milk ELISA. Herds were bulk milk sampled on three occasions, twice, a week apart in March 2017 ($n = 430$ and $n = 99$) and once in October 2017 ($n = 412$). The concentration of liver fluke antibodies was estimated using the IDEXX Fasciolosis Verification ELISA (IDEXX Europe BV, Hoofddorp, The Netherlands) on these bulk milk samples. Herds were categorised according to the test instructions, with “medium” (≥ 20 % cows infected) or “strong” (≥ 50 % cows infected) results designated as production limiting. All herds were also sent a short questionnaire about awareness of liver fluke and treatment in their herds. The agreement between the IDEXX results for 99 herds sampled twice in March 2017, and between the IDEXX results for March and October for all herds was assessed with a Kappa test. There was a substantial agreement between the two March tests, kappa = 0.7 (95 % CI 0.58–0.82) and moderate agreement between the March and October samples kappa = 0.41 (95 % CI 0.34–0.48). The results of the questionnaire were linked to the IDEXX results, and the distribution of herds categorised by their IDEXX result plotted. At the March and October samplings 0/35 (0 %) and 0/27 (0 %) Canterbury herds, 248/395 (63 %) and 193/385 (50 %) of West Coast herds had a production limiting seroprevalence of liver fluke infection. Mapping showed that West Coast herds with a production limiting infection were clustered in coastal areas, whereas those without, were clustered in inland valleys. The odds of a coastal West Coast dairy herd having a production limiting seroprevalence of liver fluke were 10.7 (95 % CI, 6.6–17.3) times that of an inland herd in March and 8.6 (95 % CI, 5.4–13.8) times in October. There was no effect on IDEXX ELISA SP% ($p = 0.92$) of herds which were treated for liver fluke at dry off soon after the March test compared to their SP% in the following October test, soon after calving.

The results show that liver fluke infection is a potentially serious problem for West Coast dairy herds especially for those on coastal river plains prone to flooding.

1. Introduction

Fasciolosis, caused by the trematode parasite *Fasciola hepatica* (liver fluke) is a worldwide problem (Vercruysse and Claerebout, 2001; Pritchard et al., 2005; Charlier et al., 2014; Kelley et al., 2020; de Waal and Mehmood, 2021) resulting in economic losses for farmed ruminants. Studies of liver fluke in New Zealand are generally sparse, with the parasite traditionally thought to be more important in some areas than others. One region recognised as having a high prevalence of liver fluke

infection is the West Coast of the South Island (Harris and Charleston, 1980; Charleston et al., 1990; Haydock et al., 2016). Economic losses are considered to occur on commercial farms when the in-herd prevalence of a disease exceeds a production-based threshold particular to that disease. A production-based threshold is defined as the level of infection that will result in a decrease in production, including weight and milk volume. For liver fluke this is thought to occur when the herd prevalence is ≥ 25 % (Vercruysse and Claerebout, 2001; Charlier et al., 2007).

A population of the intermediate host snail is critical for the

Abbreviations: BME, bulk milk ELISA test.

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maintenance of liver fluke infection. In New Zealand, two species of such snails are found, *Pseudosuccinea columella* and *Austropelea tomentosa*, with *P. columella* now being considered the most important. *Pseudosuccinea columella* was first detected in New Zealand in 1940 and was thought to have been accidentally introduced into New Zealand from North America. It has now progressively replaced the indigenous species *A. tomentosa* (Harris and Charleston, 1980; Charleston, 1997). Although it is believed that *P. columella* is present on the West Coast of the South Island, the most recent detailed study delimitating the spatial distribution of suitable intermediate host snails was in the early 1970s and at that time it was not identified there (Harris, 1974).

These mud snails prefer habitats where their feed source of benthic algae grow; shallow water, muddy substratum and limited shading. They are most active at temperatures between 12 °C and 30 °C, which is in close agreement with that required for successful development of liver fluke intermediate stages (Pullan et al., 1972). The West Coast is noted for frequent rain and flooding events on both a paddock and river valley scale, which facilitates both suitable habitats for the snails to breed as well as suitable conditions to distribute the snails, parasite eggs and metacercariae to infect neighbouring herds.

Systematic testing for the presence of liver fluke in New Zealand cattle is sporadic. Testing may include post-mortem liver inspections at slaughter, which can either report the specific presence of liver flukes or the less specific presence of liver damage, with the potential for the latter to be confused with sporidiesmin toxicity from the pasture fungus *Pithomyces chatharum* (facial eczema), which is widespread throughout much of the North Island (Cuttance et al., 2021). The validity of slaughterhouse data is also confounded by the movement of livestock to different regions during their lifespan resulting in liver fluke infected animals being identified in regions where the parasite is not endemic. More focused investigations may also be carried out at both the individual animal, using either faecal or serum samples or at the herd level, using the bulk milk ELISA (BME) test. Bulk milk ELISA testing is a relatively straightforward and inexpensive method of monitoring the infection status of dairy herds for several contagious diseases and parasites including liver fluke.

The West Coast of the South Island of New Zealand lies between latitude 41 to 43 degrees South and longitude 169 to 172 degrees East. It is bordered to the West by the Tasman Sea and East by the Southern Alps with 1600-4000 mm annual rainfall and mean monthly temperatures ranging from 5 to 18 °C. It is classified by the Köppen-Geiger climate zone classification system as Cfb (temperate, no dry season, warm summer). Effectively, all the dairy herds on the West Coast comprise spring calving cows with an average herd size of 411 cows and stocking rate of 2.21 cows per hectare, supplying milk to one dairy factory (Westland Milk Products) for processing. The lactating cow diet is pasture based but may include the use of supplementary feeding of silage in the paddock and grains or compound meals in the milking parlour. During the non-lactating period (around two to three months over the winter) the cows remain on pasture and the diet remains pasture-based, supplemented with silage harvested from the farm and with forage brassicas and swede crops fed on some farms. Liver fluke infection is considered endemic in many parts of the West Coast. However, anthelmintic treatment targeting liver fluke may only be used in the non-lactating period due to long milk withhold times after treatment.

A feature of farms on the West Coast are the presence of pakihi wetlands, which is a Māori term that refers to areas of poorly drained, infertile land, with little or no peat. These areas have been developed into farmland through drainage remediation with one common method being “humping and hollowing” (Thomas et al., 2007). Using mechanical diggers, soil is dug out to form “hollows” and placed in linear “humps” with the resulting hollows being either permanently or predominantly wet areas, creating an ideal environment for mud snail intermediate hosts of *F. hepatica*.

By contrast, the province of Canterbury lies at a similar latitude to

the West Coast but further East on the opposite side of the Southern Alps Mountain range and bordered by the Pacific Ocean to the East. Although given a similar Köppen-Geiger classification to the West Coast, Canterbury is much drier with 500–800 mm annual rainfall and the summers are generally hot with long dry periods. The soils are typically free-draining light topsoil over alluvial gravel and central pivot irrigation is a common feature of dairy farms throughout Canterbury. Canterbury has 874 herds, with an average of 803 cows and stocking rate of 3.43 cows per hectare, calving in the spring with pasture being the dominant feed during lactation and lactation ends in the late autumn or early winter. During the dry period brassicas, bulb crops and silage are commonly fed. Liver fluke infection is not considered to be endemic in Canterbury.

This study had four aims. The first aim was to assess the seroprevalence, intensity, and spatial distribution of *F. hepatica* infection in the autumn and spring of 2017 for those Canterbury and the West Coast dairy herds supplying milk to Westland Milk Products (WMP). The second and third aims were to measure the repeatability of the BME test and measure the change in the BME test results from March 2017 to October 2017 at the herd level, respectively. The fourth and final aim was to present the results of a short postal survey to determine the awareness of *F. hepatica* infection of farmers whose cows supply milk to WMP, and the anthelmintic practices used to control liver fluke on their farms.

2. Materials and methods

This was a prospective cross-sectional observation study of the seroprevalence of liver fluke infection of dairy herds from the West Coast and Canterbury regions of the South Island, New Zealand in March and October of 2017. Milk samples collected at the time of tanker collections from each spring calving dairy herd that supplied milk to Westland Milk Products (WMP), Hokitika, New Zealand, formerly known as Westland Milk Cooperative, over a two day period of each collection period were analysed. Westland Milk Products is the sole milk processor on the West Coast of the South Island and collects milk from 95 % of the dairy herds on the West Coast, in addition to a small number of Canterbury dairy herds.

2.1. Milk samples

A 50-70 ml milk sample, identified by the unique herd WMP supplier number, was collected by the tanker truck from the bulk tank milk (BTM) of each herd. The milk samples were collected over two consecutive days to ensure maximum enrolment of herds. In March 2017 (autumn), late lactation, milk samples were collected over 2 days on two separate occasions, one week apart and in October 2017 (spring), early lactation, milk samples were collected from a single two-day period. The samples were stored in a refrigerator on the day of collection and transported with cool packs to Massey University, Palmerston North, where they were held at 4 °C overnight or stored at –20 °C for no more than 5 days, then thawed at 4 °C prior to analysis. Westland Milk Products also provided the supplier number, region, and map coordinates of the milking shed for each herd.

2.2. Bulk Milk ELISA testing

The concentration of *F. hepatica* antibody specific to the f2 antigen in the BTM samples was quantified using a commercial ELISA test (IDEXX Fasciolosis Verification, IDEXX Europe BV, Hoofddorp, The Netherlands) including positive control (PC) and negative control (NC) samples as per kit instructions. Both the autumn and spring milk samples were thawed and analysed by the same technician no more than 5 days after arrival. The colour reaction is read as an optical density (OD) at 450 nm using a microplate spectrophotometer (BioTek Epoch 2 m Vermont, USA) and the sample-to-positive percentage ratio (S/P%) is calculated with this

formula:

$$SP\%_{sample} = 100 \times \left(\frac{OD_{sample} - OD_{NC}}{OD_{PC} - OD_{NC}} \right)$$

where NC denotes negative control and PC positive control, both supplied with the kit.

Depending on the SP%, the results were categorised using the manufacturers' recommendations as "no or very weak", "low", "medium", and "strong" infestation, where $SP\% \leq 30$ is evidence of "no, or very weak" liver fluke infection within the herd (0 % of cows infected), a "low" result, $30 < SP\% \leq 80$, is evidence of a low seroprevalence (<20 % cows infected) of liver fluke infection within the herd, a "medium" result, $80 < SP\% < 150$, is evidence of a low to moderate seroprevalence of liver fluke infection (≥ 20 % but ≤ 50 % cows infected) of liver fluke infection within the herd and a "strong" result, $SP\% \geq 150$, is evidence of a high seroprevalence of liver fluke infection (>50 % cows infected) within the herd.

Herds returning a "medium" or "strong" IDEXX ELISA result, $SP\% > 80$, indicating ≥ 20 % cows were infected, were categorised as likely to have a production limiting infection (Verduyck and Claerebout, 2001; Charlier et al., 2007).

2.3. Survey questionnaire

A questionnaire was included with the IDEXX *F. hepatica* ELISA result letter sent in May 2017 to all farmers whose herd BTM was sampled and analysed using the BME in March 2017. The survey questionnaire was evaluated by peer review and judged to be low risk and approved by the Human Ethics Committee, Massey University. A cover note accompanied the postal survey, describing its purpose, assuring anonymity, and identifying the researchers with their contact details. Farmers were asked to voluntarily supply their milk supplier number, which when made available allowed the questionnaire to be linked to the BME test result and the GPS coordinates of the farm. Where a farmer owned more than one herd and gave the milk supplier numbers for each of those herds, the questionnaire results were recorded against each unique supply number e.g., if a farmer supplied three milk supplier numbers, then the results were entered as three individual herds.

The survey contained 6 closed questions with tick boxes next to the available answers. The respondents were asked about,

1. Their awareness of liver fluke presence on their farm in the previous five years,
2. Whether they drenched the herd specifically targeting liver fluke,
3. If they drenched, what was the proportion of the herd treated (<25 %, 25–75 %, >75 %, 100 %),
4. Whether calves and heifers were drenched with a product specifically targeting liver fluke,
5. Whether they were interested in attending a workshop or seminar on liver fluke, and,
6. Whether they were interested in being part of a further study of the effect of liver fluke on milk production in their herd and to provide their contact details if they were interested.

A blank section was provided for the farmer to add any other comments concerning liver fluke.

2.4. Statistics

The unweighted Kappa test was used to measure the agreement in BME categorisation between the first and second sampling for the 99 herds sampled twice in the autumn one week apart and between the March 2017 and October 2017 samplings for those herds sampled twice 6 months apart. The Kappa statistic varies from 0 to 1, where 0–0.2 indicates no to slight agreement, 0.2–0.4 indicates fair agreement, 0.4–0.6 indicates moderate agreement, 0.6–0.8 indicates substantial agreement, and 0.8–1.0 indicates almost perfect agreement.

Survey questionnaire data were entered into an Excel spreadsheet (Microsoft®), with herds identified by their Westland Milk Cooperative milk supplier number or left blank if the author of the survey responses preferred it withheld. For herds with a supply number the data was linked to the BME results for that herd. The survey data were summarised as proportions and a 95 % confidence interval given.

Pearson's Chi squared was used to test whether there was a significant association between farmer treatment (drench) choices and their BME result in March 2017. The two-sample *t*-test was used to test whether the mean change in the BME SP% from March to October was the same for herds that treated with an anthelmintic active against liver fluke and those herds that did not.

Maps were constructed using the World Geodetic System 1984 (WGS84) projection, showing the spatial distribution of the sampled herds using the GPS coordinates of the milking parlour supplied by Westland Milk Products. A shapefile of New Zealand rivers was superimposed on the map of sampled farms to show the relationship between herds and waterways. Herds were grouped depending on whether they were situated near the coast or more inland and the proportion with a production limiting infection calculated. An odds ratio, with 95 % confidence interval, was calculated to estimate the probability of a coastal herd having a production limiting infection compared to an inland herd, for both the March and October samplings.

3. Results

The locations of the dairy herds extended from 40.164° to 44.041° latitude South and 169.943° to 172.456° longitude East. The March 2017 sampling included 395 herds from West Coast and 35 from Canterbury, whilst the October 2017 sampling included 377 herds from West Coast and 26 from Canterbury. Of these, 399 herds were sampled both in March and October.

The results of the IDEXX testing for March and October 2017 are shown in Table 1.

3.1. Repeatability of a BME

For the 99 herds repeatedly sampled in autumn the kappa = 0.7 (95 % CI 0.58–0.82), which indicates a "substantial" agreement between the two test points. The counts for each category are shown in Table 2. However, there was one herd classified as "strong" in the first sample and "no or very weak" one week later.

3.2. Agreement between march and October 2017 samplings

There were 399 herds sampled both in March and October 2017, of which 372 were from the West Coast and 27 from Canterbury. There was little change in the herd liver fluke seroprevalence categories for the

Table 1

IDEXX categorisation for herd prevalence of liver fluke for herds supplying milk to West Westland Milk Cooperative in March and October 2017.

Month	Region	IDEXX bulk milk ELISA category				Total
		No or very weak	Low	Medium	Strong	
March	Canterbury	35 (100 %)	0	0	0	35
	West Coast	98 (24.8 %)	49 (12.4 %)	62 (15.7 %)	186 (47.1 %)	395
October	Canterbury	25 (92.6 %)	0	2 (7.4 %)	0	27
	West Coast	123 (31.9 %)	71 (18.4 %)	86 (22.3 %)	105 (27.3 %)	385

Table 2
IDEXX bulk milk ELISA categories for 99 West Coast herds tested one week apart in March 2017.

	BME category	Week 2				Total (%)
		No or very weak	Low	Medium	Strong	
Week 1	No or very weak	27	6	0	0	33 (33.3 %)
	Low	1	7	3	0	11 (11.1 %)
	Medium	0	1	4	4	9 (9.1 %)
	Strong	1	0	4	41	46 (46.5 %)
	Total (%)	29 (29.3 %)	14 (14.1 %)	11 (11.1 %)	45 (45.5 %)	99

Canterbury results with all 27 samples being “no or very weak” in March and 2/27 (7.4 %) being “medium” in the October and the rest still “no or very weak”. The West Coast herd liver fluke seroprevalence category results are shown in [Table 3](#) and were more dynamic.

The Cohen’s kappa analysis was 0.41 (95 % CI 0.34–0.48) which indicates a “moderate” agreement between the two sample points, with 211/372 (57 %) of herds having the same IDEXX BME liver fluke categorisation at both tests. There was a mean SP% reduction of 28.7 % points from 123.2 % points in March 2017 to 94.5 % points in October 2017, although this decrease did not always change the IDEXX BME liver fluke categorisation for individual herds. Overall, there was an increase in the seroprevalence of herds classed as “no or very weak”, “low” or “medium” from March to October 2017 and a decrease in the seroprevalence of herds classed as “strong”, [Table 3](#). At the March 2017 sampling, 0/35 Canterbury herds and 248/395 (63 %, 95 % CI 58–67 %) of West Coast herds had a production limiting seroprevalence of liver fluke infection. This dropped to 191/385 (50 %, 95 % CI 45–54 %) of West Coast herds by October 2017, [Table 1](#).

Table 3
Herd liver fluke prevalence categorisation for 372 West Coast dairy herds sampled in March 2017 and October 2017, using the IDEXX bulk milk ELISA (BME) test.

	BME category	October 2017				Total (%)
		No or very weak	Low	Medium	Strong	
March 2017	No or very weak	75	10	8	3	96 (25.8 %)
	Low	17	21	7	0	45 (12.1 %)
	Medium	18	18	20	4	60 (16.1 %)
	Strong	7	21	48	95	171 (46.0 %)
	Total (%)	117 (31.5 %)	70 (18.8 %)	83 (22.3 %)	102 (27.4 %)	372

3.3. Survey questionnaire

A total of 156 completed questionnaires were returned ([Dowling, 2023](#)), representing 168 herds, and for 161/168 (96 %) of herds a corresponding farm supply number was supplied by the respondent. The survey analysis was restricted to those surveys with a supply number. However, not all questions were answered by some farmers.

Of those respondents providing a milk supplier number, 157/161 (98 %) herds were from the West Coast and 4/161 (2 %) were from Canterbury. A total of 136/160 herds (85 %, 95 % CI 79–90 %) were aware of liver fluke being present on the farm in the previous five years and of the herds that were aware 110/136 (81 %, 95 % CI 73–87 %) treated with an anthelmintic specifically targeting liver fluke. Interestingly, out of the 24 respondents that were not aware of liver fluke being present on their farm, 2/24 (8 %, 95 % CI 2–26 %) still said they treated for liver fluke. Of the 112 herds that did treat with a flukicide 106/112 (95 %, 95 % CI 89–98 %) treated all the herd, 3 farmers reported treating less than 25 % of the herd, 2 treated more than 75 %, and 1 treated between 25 and 75 % of the herd. Treating cattle less than one year of age with an anthelmintic specifically targeting liver fluke occurred on 106/154 (69 %, 95 % CI 61–76 %) of farms and treating cattle aged one to two years occurred on 111/156 (71 %, 95 % CI 64–77 %) of farms.

There was a strong association between the survey response to the question “Did you treat (drench) the cows with a product that specifically targets liver fluke” and the March BME category ($\chi^2 = 31.1$, $p < 0.0001$), with herds which said they treated tending to be categorised as “strong” and herds which said they did not, more likely to be categorised “no or very weak”. There were 99 respondents to the survey identified at the March 2017 sampling as having a production limiting infection, i.e., BME category = “medium” or “strong”. Of these, 82 treated the cows with a product that specifically targets liver fluke and 17 did not. For those herds which said they treated, the mean SP% fell 52 % points from 186 to 133, from the March to the October sampling and for those herds which did not treat, the mean SP% fell 50 % points from 194 to 144 ($p = 0.92$, two-sample t -test).

3.4. Spatial distribution

The spatial distribution of sampled herds with GPS coordinates is shown in [Fig. 1](#) and clearly shows that dairy herds on the West Coast are intimately related to rivers, whereas those from Canterbury are not. This likely reflects the topography of the West Coast where the only accessible, farmable land is along the river valleys separated by steep bush-covered hillsides.

The spatial distribution of sampled herds categorised by BME seroprevalence category for March 2017 ([Fig. 2](#), [Table 4](#)), showed pronounced clustering of herds with the herd seroprevalence of infection categorised as “medium” or “strong” in coastal plains and valleys such as Karamea, Westport, Hokitika, Harihari, and Whataroa, except Fox Glacier, whilst herds along the inland valleys from Greymouth to Murchison (along the Grey and Inangahua rivers), and from Murchison to Springs Junction (along the Maruia river) had more herds categorised as “low” or “no or very weak”. Herds present on the Canterbury plains were almost exclusively categorised as “no or very weak”.

In total there were 400 herds with GPS coordinates. Of these there were 393 herds (371 on the West Coast and 22 from Canterbury) which had BME results for March 2017 ([Fig. 2](#), [Table 4](#)), and 375 farms (357 on the West Coast and 18 from Canterbury) for October 2017 ([Fig. 2](#), [Table 5](#)).

The odds of a coastal West Coast herd, i.e., from areas A, D or FE in March having a herd production limiting seroprevalence of liver fluke are 10.7 (95 % CI, 6.6–17.3) times that of an inland herd, i.e., from areas B or C, and in October is 8.6 (95 % CI, 5.4–13.8).

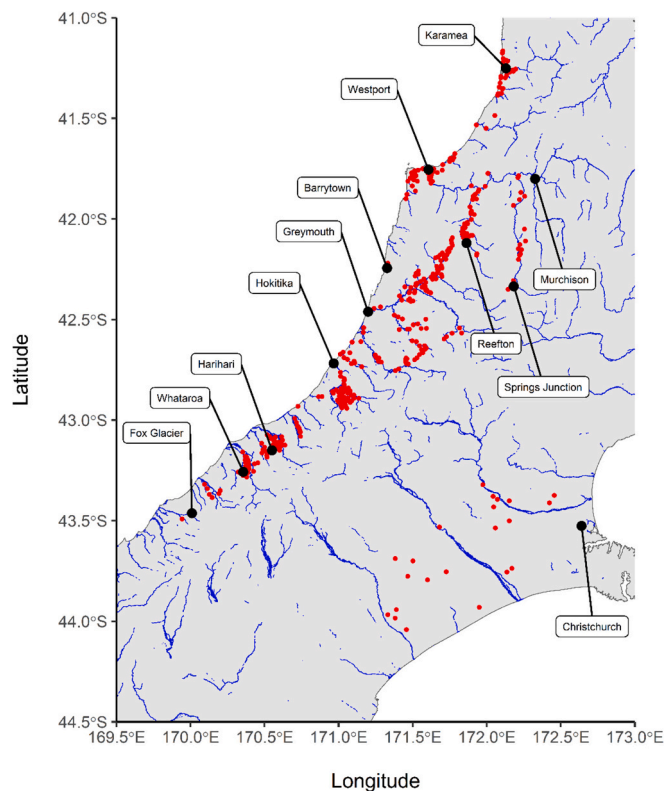


Fig. 1. Spatial distribution of sampled herds, red dots, superimposed on a map of the major rivers of the area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

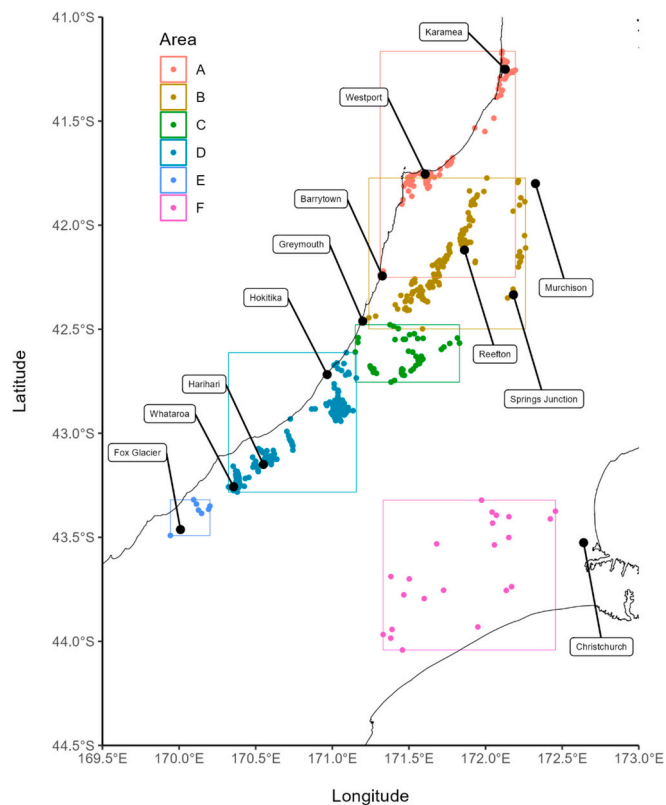


Fig. 2. Amalgamation of sampled herds into areas A to F, based on whether they were coastal or inland valleys and if inland which rivers they were associated with.

4. Discussion

These results emphatically support the findings from previous studies (Charleston et al., 1990; Haydock et al., 2016) that liver fluke is indeed a common parasitic infection of dairy cattle on the West Coast of South Island, New Zealand. Clustering of herds based on herd seroprevalence of infection was evident in both seasons with the IDEXX BME proving to be a highly repeatable test. Of the farmers on the West Coast who returned survey questionnaires, most were aware of liver fluke, with 85 % of farmers reporting that they had been aware for the past five years and most are using liver fluke specific anthelmintics at dry off.

The kappa test for the two tests a week apart gave substantial agreement and demonstrated that the IDEXX BME is a highly repeatable test, when used in dairy herds to detect infection with liver fluke. The one herd with a spurious result (“strong” in Week 1 and “no or very weak” in Week 2) may have removed cows that had high antibody titres between the sampling periods or there may have been an error in data recording such that the herd supply number was incorrectly recorded for one of the weeks. No attempt was made to determine if the same cows were present in each herd at each of the two sample points. That result aside, farmers and their advisors should feel confidence in the repeatability of this test.

The test characteristics of the IDEXX BME ELISA were not assessed in this study. However, the Canterbury herds provided a useful negative control for the March and October samplings, as this region is not considered to have an environment that would support the intermediate host snails, being drier and having free draining soils. In the autumn, all 35 herds in Canterbury were categorised as “no or very weak” and in the spring 24/26 (92 %) were still “no or very weak” with 2/26 (8 %) having a “medium” category infection. The introduction of intermediate host snails infected with liver fluke onto the land grazed by these two herds between autumn and spring 2017 is highly unlikely. However, the introduction of cows carrying liver fluke infection is entirely possible. This could be easily accomplished by purchasing or moving cows that have spent time grazing on West Coast farms infected with liver fluke, as some farmers own herds in both regions and may move cattle between them, although there is no data to support this hypothesis.

The failure to find a difference in the SP% change from March to October 2017 for herds that treated with an anthelmintic specifically targeting liver fluke and herds that did not, was a surprising result. Assuming the March 2017 treatment was effective, there should have been sufficient time for the SP% to have declined by October 2017 (Castro et al., 2000; Munita et al., 2019), which indicates that the treated herds had likely become reinfected and had reached similar herd infection seroprevalence to the herds that were not treated. This would suggest that for fluke treatment to be effective at dry off, West Coast cows need to be taken off pasture after treatment. This clearly is not an option and may explain why 19 % of farmers who were aware they had a fluke problem indicated they did not treat, possibly recognising the futility of treating cows which are continuously exposed to infection.

Our limited understanding of the liver fluke lifecycle in New Zealand is that metacercariae build-up in the autumn but do not survive the winter (Harris and Charleston, 1976). The evidence from this study would indicate treated cows are becoming infected again by October (spring) possibly due to overwintering of infected snails, metacercariae being infective for some or all the winter period, or immature flukes continuing their development, due to being unaffected by the anthelmintic choice. Although, infected snails can survive a mild winter (Luzon-Pena et al., 1994), redia development only recommences once the snail is active in the spring, which is more likely to result in summer infection of cows, which is later than the October sampling.

The spatial clustering of herds categorised as “strong” or “no or very weak” herd seroprevalence infection category (Tables 4 and 5) observed in this study is also a feature of studies in Denmark (Olsen et al., 2015), the United Kingdom (McCann et al., 2010), Northern Ireland (Byrne et al., 2018), Ireland (Selemetas et al., 2014), Sweden (Novobilsky et al.,

Table 4

Numbers of herds in each area, categorised by IDEXX ELISA result, and proportion with production limiting infection for March sampling.

Description	Map area	Farms(n)	IDEXX ELISA category				Production limiting (%)
			Strong	Medium	Low	No or very weak	
Karamea to Barrytown, coastal	A	72	48	14	6	4	86.1 %
Grey, Inangahua and Maruia rivers, inland	B	114	17	18	18	61	30.7 %
Taramakau river, inland	C	45	15	8	10	12	51.1 %
Hokitika to Whataroa, coastal	D	133	94	20	9	10	85.7 %
Fox Glacier, coastal	E	7	1	0	1	5	14.3 %
Canterbury, inland	F	22	0	0	0	22	0.0 %
Total		393	175	60	44	114	59.8 %

Table 5

Numbers of herds in each area, categorised by IDEXX ELISA result, and proportion with production limiting infection for October sampling.

Description	Map area	Farms(n)	IDEXX ELISA category				Production limiting (%)
			Strong	Medium	Low	No or very weak	
Karamea to Barrytown, coastal	A	68	30	17	12	9	69.1 %
Grey, Inangahua and Maruia rivers, inland	B	112	8	9	33	62	15.2 %
Taramakau river, inland	C	46	6	14	4	22	43.5 %
Hokitika to Whataroa, coastal	D	125	53	39	18	15	73.6 %
Fox Glacier, coastal	E	6	1	0	1	4	16.7 %
Canterbury, inland	F	18	0	1	0	17	5.6 %
Total		375	98	80	68	129	47.5 %

2015), Mexico (Villa-Mancera and Reynoso-Palomar, 2019) and Germany (Fanke et al., 2017). Given the spatial clustering observed in this study, with herds on coastal river plains having a much higher odds of having a production limiting herd seroprevalence of liver fluke infection than those herds from inland valleys and further up the river catchments, then it is likely that flooding events, and the presence of wetlands are important determinants of liver fluke infection on farms from the West Coast.

In this study, a cut point of $\geq 20\%$ of cows being infected in a herd was used to define a production limiting infection. This is slightly lower than that used by other studies where a production limiting effect was considered to occur when 25 % or more of the herd was infected (Veracruz and Claerebout, 2001; Charlier et al., 2007). This slight disparity was due to the interpretation of the IDEXX BME SP% result, which gives four infection categories with the “medium” and “strong” categories equating to a herd seroprevalence $\geq 20\%$ infected cows. We believe that 20 % and 25 % are sufficiently similar that the production limiting results presented in this study and those presented in international studies can legitimately be compared. In the current study, 63 % of West Coast herds in the autumn and 50 % in the spring had infection at a level likely to be production limiting, which is lower than the 72–86 % reported in England (McCann et al., 2010) and Wales (Salimi-Bejestani et al., 2005); but similar to other studies in Ireland, northern Germany, England, Belgium and Northland in New Zealand (Salimi-Bejestani et al., 2005; McKay, 2008; Bennema et al., 2009; Kuerpick et al., 2012b; Kuerpick et al., 2012a; Byrne et al., 2018); and greater than Switzerland, Austria and Sweden (Novobilsky et al., 2015; Kostenberger et al., 2017; Frey et al., 2018). Notwithstanding any differences in ELISA tests and test interpretation used in the referenced studies, it is apparent that the seroprevalence of liver fluke infection on the West Coast is high by international standards.

The use of anthelmintics is a common feature of liver fluke management plans in many countries (Knubben-Schweizer et al., 2010; Charlier et al., 2012; Bloemhoff et al., 2015; Selemetas et al., 2015) and appears to be common on the West Coast of New Zealand, with 81 % of farmers who were aware they had a liver fluke problem indicating that they treated adult cows for liver fluke. Furthermore, this study showed a strong association between whether the farmer treated the cows for fascioliasis in the autumn and the autumn BME result. Of those farmers whose herds had a positive result for liver fluke, most were likely to treat cows, with almost all treating the entire herd. Unfortunately, in that

year, the results letter and survey questionnaire were sent at the same time, and this may have influenced the decision to treat or how the farmer answered the relevant survey question. The concern about the potential impacts of liver fluke, as well as the commercial marketing of anthelmintics to dairy farmers during the dry-off period, may also be the reason why 2/24 (8 %) of herds, where the farmer was not aware they had a liver fluke problem, still decided to treat which is not an insignificant cost.

It is important to remember that any change in the seroprevalence of liver fluke infection from March to October for herds enrolled in this study may not entirely be due to changes in exposure to metacercariae. Additional causes include removal of infected cull cows at or near the end of the lactation period; the addition of heifers or “carry-over” adult cows at the start of lactation; anthelmintic treatment in the “dry” (non-lactating) period; seasonal factors affecting the intermediate host snails and lifecycle stages of liver fluke in the environment; or the cows being grazed on forages with either a lower or greater metacercarial infectious load compared to the lactation period. These considerations are all relevant but were beyond the scope of this study.

4.1. Conclusion

Taken together, the results of this current study have determined that liver fluke infection is common in dairy herds on the West Coast, with over 50 % having a herd seroprevalence of infection that likely impacts production. The results also suggest that current intervention practices are having a limited impact on the *F. hepatica* life cycle in dairy cows in the West Coast region of New Zealand. Further studies are needed to gain a better understanding of the epidemiology of the life cycle of liver fluke in this region so that control measures and disease modelling can be better used to prevent this disease.

Ethics statement

All studies were approved by the Massey University animal and human ethics committees.

Ethics

This paper abides by the guidelines for ethical publishing as presented in the Veterinary Parasitology Regional Studies website.

CRedit authorship contribution statement

A. Dowling: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **L. Howe:** Writing – review & editing, Supervision. **I. Scott:** Writing – review & editing, Supervision. **W. Pomroy:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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