New Zealand Fisheries Assessment Research Document 92/11

Foveaux Strait oyster (*Tiostrea chilensis*) assessment, 1992

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August 1992

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1. INTRODUCTION

Bonamia was diagnosed as the cause of localised high mortalities of oysters in Foveaux Strait in 1986. The disease continued to spread and mortality from the disease progressively reduced the size of the oyster population (Cranfield *et al.* 1991). In 1991 the disease still appeared to be spreading to the few remaining uninfected parts of the oyster population that had commercially acceptable densities of oysters. Because of the mortality that was likely to follow this spread it brought into question whether the surviving oyster population could support any fishery at all.

The oyster population was surveyed between 17 February and 6 March 1992 to determine the numbers and distribution of oysters and the distribution and prevalence of infection by *Bonamia*. *Bonamia* has an annual pattern of infection in the oyster that makes it possible to measure infection levels of *Bonamia* simply and reliably only after *Bonamia* invades haemocytes throughout the oyster tissue following a proliferation phase in the gonad in the early summer, (see Hine 1991a, 1991b). Thus, the earliest time of year that prevalence of *Bonamia* could be measured reliably from cells present in the blood was February. Surveying oyster numbers and *Bonamia* infection in late February, meant that it would be unlikely any decision based on the analysis of the results could be made before April. In the meantime, the Minister of Fisheries allocated an interim quota of 400 sacks per vessel to be taken only from beds in areas A, H, K, and L (Fig 1).

1.1 Overview

The survey showed that the oyster population was 319 million oysters (95% CI 257-381 million). The population over the same area surveyed 18 months ago was twice the size. The population in that area in 1975 was five times this size (Table 2). Infection by *Bonamia* was lower and areas of moderate to heavy infection were limited to the north of Stewart Island and northern Foveaux Strait. The Current Annual Yield (CAY) calculated using the reference exploitation rate for 1975 was 23 000 sacks. Before setting catch levels, consideration should be given to continuing mortality from *Bonamia* significantly reducing the yield. The population is now smaller than ever before and is below 20% of the virgin stock. Survival of the fishery would be more likely if the stock was not reduced further by fishing. Any exploitation now will tend to be focused on the two or three areas where oysters attain "commercial" densities.

1.2 The fishery

Oysters are dredged by 23 vessels, 18–24 m in length, that are based in Bluff. The fishery area extends from a line between East Cape, Stewart Island and Slope Point, South Island in the east and Ruggedy Island to Centre Island lighthouse to Oraka Point in the west (Fig. 1). The season is usually from 1 March to 31 August. In 1992 it was closed until the results of the survey were analysed. At this stage the Minister of Fisheries has permitted a limited season from 16 March to 16 April until the results are known.

1.3 Literature review

Past work was briefly reviewed by Cranfield *et al.* (1991).

Results from the 1992 oyster survey are reported in Appendix 1, and the results of the *Bonamia* sampling in 1992 were reported by Hine and Wesney (1992).

2. REVIEW OF THE FISHERY

2.1 Catch and catch rate

Catch is controlled by a quota for each boat. This was 5 000 sacks before the *Bonamia* epidemic (1986) and was progressively reduced to 2000 sacks by 1990 (Table 1).

Table 1: Oyster catch, total quota, and the average catch rate 1986-91

	Catch (sacks)	Total quota (sacks)	Vessel quota (sacks)	Mean catch rate (sacks per hour)
1986	77 880	115 000	5 000	10.32
1987	61 544	64 400	2 800	10.90
1988	87 477	92 000	4 000	10.00
1989	85 029	92 000	4 000	10.70
1990	46 114	46 000	2 000	6.40
1991	54 000	46 000	2 000	5.80

In 1991, fishers dredged a "firebreak" between the uninfected beds to the east and the infected beds to the west. The catch from the firebreak was above the quota as an incentive to fish. Thirteen vessels caught a total of 3 770 sacks there.

The area of commercial beds has been decreasing since the outbreak of *Bonamia* in 1985, but the catch rate did not reflect the reduction in stock until 1990.

2.2 Maori and recreational fishing

None known.

3. RESEARCH

3.1 Resource surveys

Resource surveys were conducted between 1960 and 1962, and in 1974, 1975, 1990 (Cranfield *et al.* 1991) and 1992 (Appendix 1).

3.2 Population size estimates

A dredge survey mapped oyster densities in 1960-62 and the population was estimated after these densities were calibrated by divers. The population size was estimated in 1974 and 1975 in a mark recapture experiment covering the entire commercial fishery, and again in 1990 by a stratified random dive survey. The 1992 estimate was made from a grid pattern dredge survey and used a dredge efficiency that came from calibrating a similar grid pattern dredge survey in 1990 (Appendix 1). Changes in the distribution of oysters between 1990 and 1992 are shown in Figure 2. Estimates of population size are given in Table 2.

Table 2: Population size estimates for legal-size oysters (≥ 58 mm) in Foveaux Strait. Pre-1992 estimates are from Cranfield *et al.* (1991); 1992 estimate is from Appendix 1.

Year	**Population (millions)**	**CV (%)**
1960–62	1400	?
1974	1800	20
1975	1500	11
1990	632	13
1992	319	10

The population appears to have been in a relatively steady state before the *Bonamia* epidemic began (fishers' reports of mortality suggest the epidemic began in 1985) and has declined steadily since.

3.3 *Bonamia* studies

Bonamia was identified as the cause of mass mortalities in 1986 (Dinamani *et al.* 1987). Major sampling surveys were conducted in 1986, 1987, 1990, and 1992; sampling was on a smaller scale in the intervening years (Cranfield *et al.*1991). Hine and Wesney (1992) reported the results of the 1992 survey and prevalence data are given in Appendix 1. These investigations showed a progressive spread in the area of infection and subsequent mortality, which by 1991 had encompassed the entire area of oyster distribution. In 1992, the epidemic appeared to be on the wane except in area H. Changes in the prevalence of infection by *Bonamia* between 1990 and 1992 are shown in Figure 3.

The spread of infection is shown in changes in the area (indexed to 1990 and excludes area H as this area was not sampled for *Bonamia* before 1992) of moderate or heavy prevalence of *Bonamia.* These areas were (presumably) 0 km^2 in 1984, 199 km^2 in 1987, 533 km^2 in 1990, and 88 km^2 in 1992 (Appendix 1).

Hine (1991a) established that *Bonamia* in oysters in Foveaux Strait undergoes rapid growth and division in a proliferation phase between December and May with large numbers of the parasite being released from lysed haemocytes. During this period most parasites were extracellular and oyster mortality became high from late January. Bý June *Bonamia* was largely intracellular in haemocytes and in a plasmodial form which were frequently necrotic. Oyster mortality from *Bonamia* between June and December was low. The 1990 survey was carried out in July after the period of mortality in that year. The 1992 survey was completed in February and early March after probably one third of the mortality from *Bonamia* in 1992 had occurred. Thus in the 18 months between the surveys the oyster population had been exposed to 4/3 of two episodes of mortality from *Bonamia.* The 1990 oyster population was estimated to be 632 million; the 1992 oyster population was estimated to be 319 million. Fishing between the completion of the 1990 survey and the end of the fishing season (July to the end of August) removed 10 million oysters; fishing in 1991 removed 54 million oysters. Assuming that other sources of oyster mortality were balanced by recruitment over this period, the remaining decline in the oyster population was due to *Bonamia.*

The annual percentage mortality from *Bonamia* over this period was:

$$\left[\frac{632 - (319+10+54)}{632}\right] x \frac{3}{4} = 0.295$$

3.4 Yield estimates

3.4.1 Estimation of Maximum Constant Yield (MCY)

An estimate of B_0 is not available. Furthermore, because of the effects of *Bonamia*, reliable estimates of B_{av} are not available. Therefore, MCY cannot be determined.

3.4.2 Estimation of Current Annual Yield (CAY)

CAY was estimated from the Baranov catch equation (Method 2 of Annala 1992) where the fishing mortality occurs over a short period at the beginning of the year.

$$CAY = (1-e^{-F_{ref}})B_{beg}$$

B_{beg} was set equal to the population estimate of 319 million oysters from the 1992 dredge survey. In the 1991 assessment the estimated exploitation rate of 0.073 in 1975, was used as an estimate of F_{ref} (Cranfield *et al.* 1991). As it is an exploitation rate this is really an estimate of $(1-e^{-F_{ref}})$, so

$$\begin{aligned} CAY &= .073 * 319 \times 10^6 \text{ oysters} \\ &= 23 \times 10^6 \text{ oysters (95\% CI } 18 - 28 \times 10^6) \\ &= 23\ 000 \text{ sacks (95\% CI } 18\ 000 - 28\ 000 \text{ sacks)} \end{aligned}$$

The level of risk to the stock by harvesting the population at the estimated CAY cannot be determined.

4. FACTORS MODIFYING YIELD ESTIMATES

Given the current state of the stock, the CAY estimate needs to be modified by the following factors when determining catch levels:

4.1 Continuing mortality from *Bonamia* during the 1992 season

Bonamia will continue to affect the oyster population during the oyster season. The oyster population in early March 1992 was estimated to be 319 million oysters. This population will be reduced due to mortality from *Bonamia* in the remaining 2/3 of the mortality period which ends in June. Should mortality from *Bonamia* continue at the same rate as in the previous 18 months, then the population will be reduced by 319 million x 2/3 x 0.295 = 62.7 million oysters at the end of the 1992 oyster season. These calculations suggest that *Bonamia* could remove 2.7 times the estimated CAY during the oyster season. As the prevalence and intensity of infection by *Bonamia* was lower in 1992 over much of the oyster population than in 1990 (Fig. 3 and Appendix 1), the mean mortality for the last 18 months will probably overestimate mortality in 1992.

An alternative method of calculating *Bonamia* mortality would consider just the population that has a moderate or heavy prevalence of infection in 1992. As in previous years many oysters within this population are infected so intensely that they will die. The oyster population of the 88 km^2 area with a moderate to heavy prevalence of infection by *Bonamia* was estimated to be 53 million oysters (95% CI 28.4-77.4 million). Should the remaining mortality occur at the same rate as that over the whole oyster population in the previous 18 months, then we could expect 53 million x 2/3 x 0.295 = 10.4 million oysters in this population to killed by disease by July 1992. In this scenario we could expect *Bonamia* to remove slightly under half the estimated CAY during the oyster season. Because the mortality over the previous 18 months is a mean figure derived from *Bonamia* mortality in a mixture of populations with no infection or light, moderate and high levels of infection, this figure is likely to underestimate mortality in populations with high and moderate prevalence of infection.

These calculations assume that recruitment would balance other sources of natural mortality. The number of oysters killed by *Bonamia* in the remaining part of 1992 will probably be within the range 10-62 million oysters. The wide range is a result of the uncertainty in the outcome of infection by *Bonamia*. The data do indicate that mortality from *Bonamia* in 1992, after the survey, is likely to be substantial compared to the estimated CAY, and may exceed it.

4.2 Effect of the low population size on recruitment

Spat survival depends on the density of living oysters as only those spat that settle on live oysters (or on the gastropod *Astrea heliotropum*) survive 6 months after settlement (Cranfield 1979). The results of a simulation model (Allen 1979) indicate that the oyster population will collapse if it drops below 10% of the virgin population size, even if there were no fishing. This may not happen in practice, but it suggests that recruitment (and hence a sustainable yield) is much lower than expected, and recovery of the population will be slower at the present very low population size. Fishers contend that pre-recruit strength is much greater than in the past, but have not presented any quantitative data.

4.3 Concentration of fishing on only a few populations

Only a small fraction of the total stock is now in populations of densities high enough to be fished commercially. Focusing the fishery on these populations alone may drive them to virtual extinction.

5. MANAGEMENT IMPLICATIONS

Population size has been reduced to a low level by mortality from the fishery and over the last 8 years by *Bonamia*. Current population size may be close to 10% of the virgin level, and has certainly been reduced to about 20% of the (assumed equilibrium) level of 1975. Removals at the level of the CAY estimate should allow the population to at least maintain its size and possibly rebuild, but it depends largely on the future course of *Bonamia*. Oysters remaining in areas depleted by the parasite are likely to be resistant, and may provide the basis for rebuilding of the stock. Reducing oyster density in the remaining moderate to heavily infected areas by fishing may reduce the impact of *Bonamia* on these beds as the density of water borne infective particles is reduced. However, lower oyster density may also affect oyster spat survival.

6. RESEARCH NEEDS

1. Clearly the progress of *Bonamia* and its mortality has very important implications for the fishery. This will require monitoring in 1992 and 1993 to determine the course of the disease.

2. There is some indication that moderate to heavy prevalence of infection was confined to areas of oysters above a threshold density. This could be experimentally evaluated by directing catching effort and measuring the effect on density and prevalence of *Bonamia.*

3. The alleged improvement in recruitment at present low population levels requires substantiation. This could be measured by the recovery of the oyster population post-*Bonamia* (eg annual population survey), or by development of a recruitment index. This would require development of an age-size key in conjunction with a representative sampling programme.

7. REFERENCES

Allen, R.L. 1979: A yield model for the Foveaux Strait oyster (*Ostrea lutaria*) fishery. *Rapports et Proces-verbaux des reunions. Conseil Permanent International pour l'Exploration de la Mer 175*: 70–79.

Annala, J. H. (comp) 1992: Report from the Fishery Assessment Plenary, May 1992: Stock Assessments and Yield Estimates. 222 p. (Unpublished report held in MAF Fisheries Greta Point library, Wellington.)

Cranfield, H. J., 1979: The biology of the oyster, *Ostrea lutaria,* and the oyster fishery of Foveaux Strait. *Rapports et Proces-verbaux des reunions. Conseil Permanent International pour l'Exploration de la Mer 175*: 44-49

Cranfield, H.J., Doonan, I.J., and Michael, K.P. 1991: Assessment of the effects of mortality due to *Bonamia* on the oyster population of Foveaux Strait in 1990 and the outlook for management in 1991. N.Z. Fisheries Assessment Research Document 91/18.(Unpublished report held in MAF Fisheries Greta Point library, Wellington.)

Dinamani, P., Hine, P.M. and Jones, J.B. 1987: Occurrence and characteristics of the haemocyte parasite *Bonamia* sp in the New Zealand dredge oyster *Tiostrea lutaria. Diseases of Aquatic Organisms 3*: 37–44.

Hine, P. M., 1991a: Ultrastructural observations on the annual infection pattern of *Bonamia* sp. in flat oysters *Tiostrea chilensis. Diseases of Aquatic Organisms*: 163–171.

Hine, P. M., 1991b: The annual pattern of infection by *Bonamia* sp. in New Zealand flat oysters *Tiostrea chilensis. Aquaculture*: 241–251.

Hine P. M., & B. Wesney, 1992: Report on a survey of *Bonamia* in Foveaux Strait oyster beds: February-March 1992. 13 p. (Unpublished report held in MAF Fisheries Greta Point library, Wellington.)

Figure 1: Map of Foveaux Strait showing the outer boundary of the licensed fishery area and the areas for statistical returns.

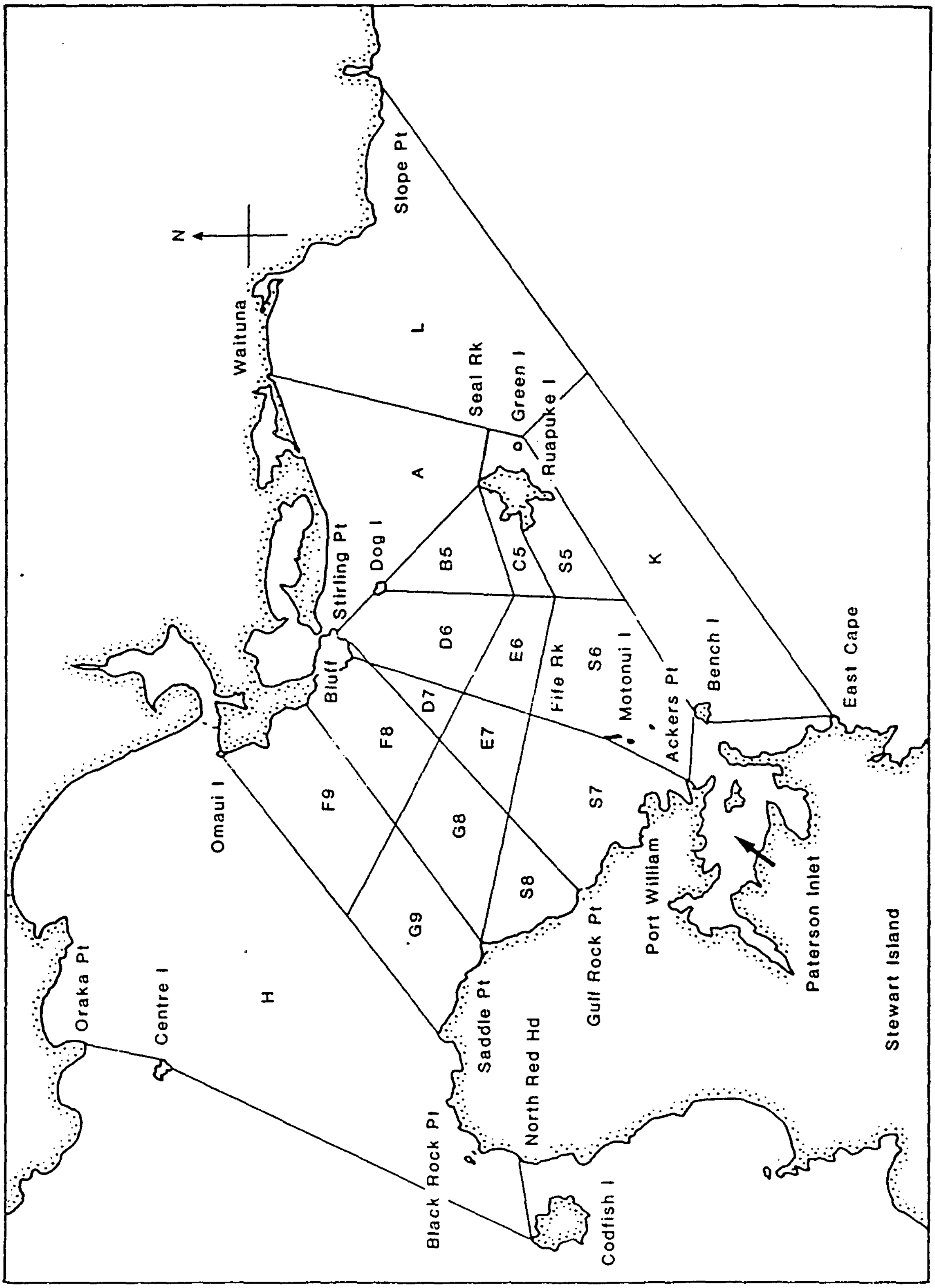


Figure 2: Catches of commercial sized oysters in 5 minute straight-line tows in grid pattern surveys by commercial vessels in 1990 and 1992. Commercial tows >400 oysters are shown black.

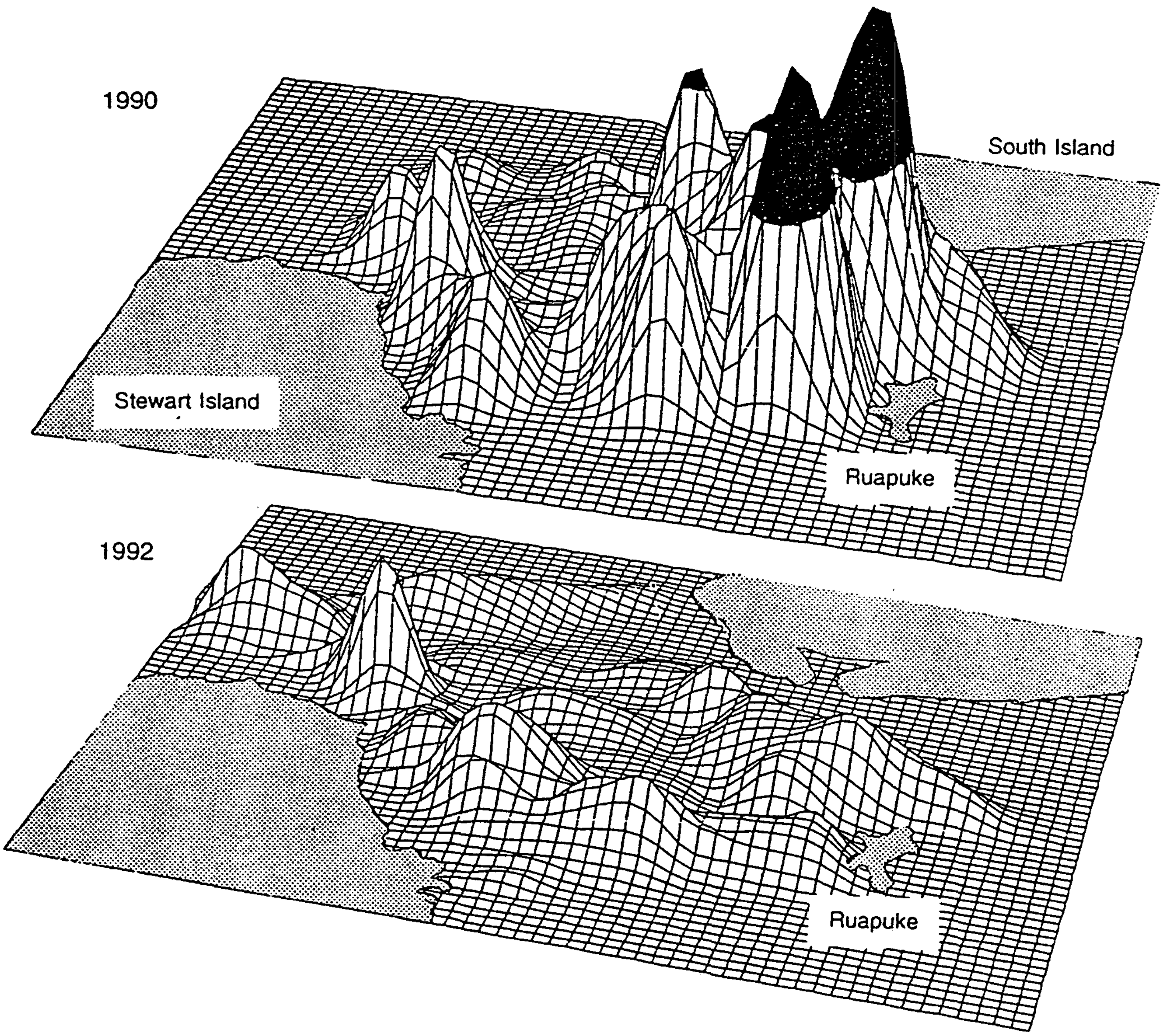
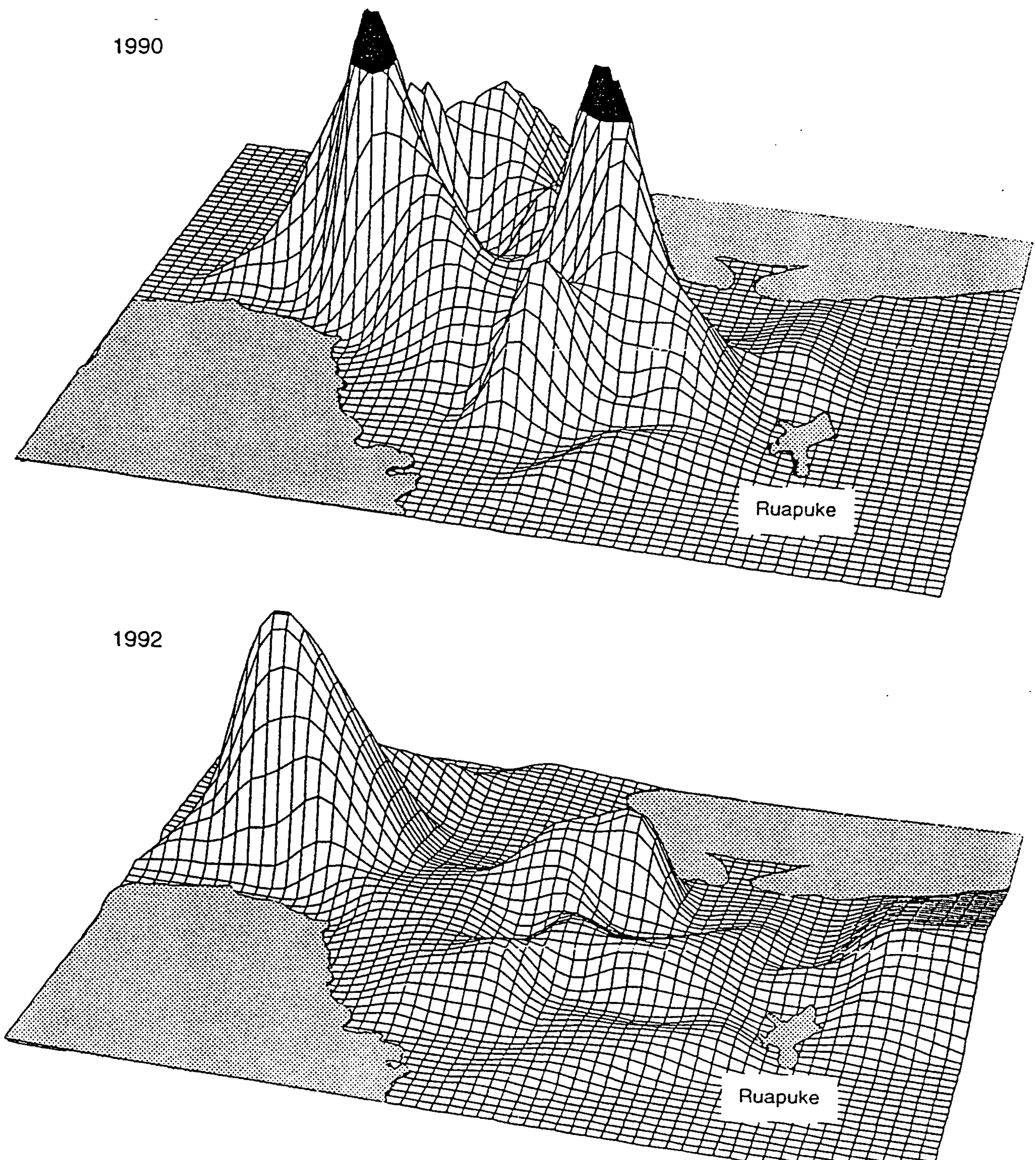


Figure 3: Percentage prevalence of infection by *Bonamia* in Foveaux Strait in 1990 and 1992. Prevalence of infection >50% shown black.



APPENDIX 1

Multi-vessel grid surveys of Foveaux Strait oysters in 1990 and 1992

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11 June 1992

1. INTRODUCTION

MAF Fisheries and the oyster industry conducted multi-vessel surveys to assess the distribution of *Bonamia* and oysters in Foveaux Strait in July 1990 and in February/March 1992. The surveys followed similar sampling protocols so their results can be compared directly. Because the 1990 grid survey could be calibrated with a 1990 dive survey, we used this calibration for the 1992 survey to give an absolute population estimate.

2. METHODS

2.1 1990 survey

The survey was conducted during 9-19 July 1990. Four vessels (skippers in brackets) were provided by Skeggs Oysters Ltd; *Golden Rose* (John Edminstin), *Golden Harvest* (Terry Dixon), *Golden Lea* (Stuart Bragg), and *Golden Quest* (Bill Johnston). These were joined in the second week by *Toiler* (Cyril MacKay) from Oyster Distributors Ltd. Each vessel had a skipper, a crew of two, and a MAF Fisheries observer.

The survey design was a grid laid out on true north-south and east-west lines. Over the main oyster-bearing area these lines were 1 nautical mile apart (233 sites), and were 2 nautical miles apart (51 sites) peripherally to this to the north-west, north-east and south (Fig. 1a).

Where the grid lines intersected, one vessel dredged a standard tow, i.e., towed one dredge (3.35 m wide) for 0.2 nautical miles in a straight line from the grid intersection, down-tide. The dredges on each vessel were all of similar dimensions. The skippers measured the 0.2 nautical mile track by radar on a mark which was, as far as possible, directly ahead or behind the tow direction and within the 3-6 nautical mile range setting.

Vessels could not dredge on foul ground, so stations that were known or suspected to be in areas of foul ground were first checked for suitable bottom. If, in the skipper's opinion, the bottom was not suitable the station was abandoned. If the dredge came fast during a tow the station was abandoned. A problem was caused by the stalked tunicate, *Pyura pachydermatina* which covered the bit bar of the dredge and reduced its efficiency in some areas. If the dredge came up with the tunicates draped over the bit bar and the dredge bag partially filled with them, then the data were recorded but were excluded from any analyses. These problems resulted in the loss of 51 stations.

To estimate the relative efficiencies of the vessels 10 grid intersections were selected as common stations and sampled by all five vessels. All stations were in the main beds south of Bluff. Vessels dredged these stations in 2 groups of 5, with each group of 5 being completed on the same day.

The data recorded for each tow were: date, time the tow started, the unique code for the grid intersection, position at the end of the tow, depth (fathoms), and the number of legal-sized oysters (i.e., those that do not fit through a ring with an inside diameter of 58 mm), the numbers of legal-sized new clocks and old clocks (definitions below), the fullness of the dredge (%), sediment type, wind force, and whether the dredge performed satisfactorily.

Clocks were empty oyster shells still held together by the ligament. A new clock was not fouled inside and had a shiny, usually green, inner surface. These were deemed to be oysters that had died since the summer of 1989/90. The remainder of the clocks, fouled on the inside, were designated old clocks (Cranfield *et al.* 1991).

Samples of 50 live legal-sized oysters were collected at 61 stations. The samples were flown to MAF Fisheries Greta Point, Wellington where the prevalence and intensity of infection were measured using counts of *Bonamia* in heart smears (Hine 1991).

2.2 1992 survey

This survey was conducted from 17 February to 6 March (extended by a week because of bad weather). It followed a design and protocol that was as similar as possible to that of the 1990 survey. There were a number of differences. Not all the same vessels, skippers, or observers used in 1990 were available in 1992; the sampling grid was expanded in 1992; and precision of navigation was improved in 1992 because GPS was used. The 1992 survey was carried out 4 months earlier in the year than the 1990 survey.

Four commercial oyster boats were used (skippers in brackets): *Golden Harvest* (Terry Dixon or Lyn Ryan), *Golden Lea* (Brian Hawke), *Toiler* (Allan Lee) and *Hirere* (Milton Roderique). *Hirere*, the only vessel not involved in the 1990 survey, was built to the same specifications as *Toiler*. The grid was oriented as in 1990, but was entirely at 1 nautical mile intervals; no 2 nautical mile spacing was used. This, and an extension of the grid to the limits of the designated fishery area, resulted in us planning to sample 870 stations. In practice, only 370 of these sites were sampled (Fig 1b) because of bad weather. However, sampling on the grid was usually extended until zero catches had been made for two consecutive tows peripherally from the last catches of oysters, so most of the area of oyster distribution was covered.

Vessels dredged on 10 common stations again so the relative efficiencies of each could be compared. The rest of the dredging protocol was the same as in 1990, but all vessels navigated, plotted tow position, and controlled tow length by GPS. Furthermore, an effort was made to improve the estimate at grid cells abandoned because of foul ground, so instead of abandoning it on the first tow (as in 1990), four extra sites were tried. Only if all these four were on foul ground was the site abandoned. Any site that needed extra tows had its oyster catch adjusted to reflect the foul ground, e.g., if two extra tows were made before ground that could be dredged was found, then the catch was adjusted by a factor of (5-2)/5 =3/5.

This assumes that there were no oysters on un-fishable ground. In practice, this method of dealing with foul ground was followed only inside the 1990 dive survey area, as these sites were dredged before the bad weather set in. In the other stations further out, to save time, if the first tow was on foul ground the whole 1 nautical mile square was abandoned (number abandoned = 28 , number adjusted = 4).

The data recorded were the same as in 1990, but also included the position at the start of tow as well as a code to identify tows repeated because of foul ground. Fifty oysters were sampled at 43 selected sites to establish the prevalence of *Bonamia*. However, the reduced density of oysters in 1992 made it impossible to catch 50 oysters at some sites even after a number of tows so these samples were limited to 40 oysters.

2.3 Analyses

2.3.1 Contour plots

Most plots, and one analysis, involved contouring the data using the New S statistical package (Becker *et al.* 1989). To ensure that contours did not wander over land, zeros were added to the data at points that lay on the coastline. Distribution of oysters, new clocks, old clocks, and prevalence of *Bonamia* were displayed using two contours.

For legal-sized oysters, the higher level contour was 400 per tow. This was estimated to be equivalent to the threshold for commercial dredging in 1990 (Cranfield *et al.* 1991). Four hundred oysters per tow is probably too high for the oyster densities of 1991, and the threshold for commercial dredging has no doubt declined further as *Bonamia* reduced oyster density. Regardless of its significance for fishing, the contour serves as a useful reference for the upper level of oyster density. The lower level contour was 100 oysters per tow which was the median number per tow in the 1990 survey.

New clocks were plotted as a mortality rate, i.e., as new clocks divided by the sum of the new clocks and oysters. This gives the mortality since the last summer. Fouling, which converts new clocks to old clocks, occurs over the summer. The contour levels used were 1 and 8% which represented the median and upper quartile values. The contour levels for old clocks were 100 and 210 per tow, which again represent median and upper quartile values. Old clocks indicate cumulative deaths for probably the last 3 years as the ligament joining the valves is thought to remain intact for 3 years in Foveaux Strait (R.J.Street, pers. comm.). Numbers of old clocks can be converted into a cumulative mortality by dividing them by the sum of the old clocks, new clocks, and oysters. This underestimates the true mortality, the bias depending on the age-as-clocks distribution and the rate of ligament breakdown. The contour levels plotted were 20% and 50%, which were about the levels associated with moderate or heavy prevalence of infection in the 1986 and 1987 *Bonamia* surveys (Dinamani *et al.* 1987).

Prevalence of infection by *Bonamia* was contoured at 10% and 25%. These levels are used as the cutoffs between light and moderate prevalence of infection; and between moderate and heavy prevalence of infection in studies of *Bonamia* (Cranfield *et al.* 1991).

2.3.2 Population estimates

Population size and variance can be estimated by treating the cells of the grid as strata with one station in each. The calculation is straightforward for the total grid if we assume that at abandoned stations the oyster density is zero or low enough not to matter. However, population estimates are also required for sub-areas of the grid (e.g., for calibration in the 1990 results section). Strictly, one should find the area for the truncated squares that have the boundary passing through them, but this was impractical.

The population estimate is given by

$$N = eI \tag{1}$$

where e is the calibration constant to convert I into an absolute population size, and

I is the population size disregarding the dredge efficiency, and is given by

$$I = \sum_i w_i \frac{C_i r_{v_i}}{D}$$

where w_i = (area supported by the grid intersection that the i^{th} tow was done at)/(number of tows made at this grid intersection),

C_i is the number of oysters caught in the i^{th} tow,

D is the area (km^2) covered by one tow and,

r_{v_i} is the relative efficiency of the vessel, v, that was used to dredge the i^{th} tow.

In a straightforward grid survey, with one tow per grid intersection, the w_i would be the area supported by that intersection. However, some sites were used to investigate relative efficiency of the vessels and so were dredged several times, and others were mistakenly dredged twice. These tows were treated as if they were the only tow on a smaller pseudo-grid, i.e., their w_i was scaled down by the number of tows performed at the site. This has the same effect as using the average catch of the tows and so makes no difference to the population estimate, but it makes minor differences to the estimate of variance.

For grids with only one tow per intersection the variance of I, $V(I)$, cannot be estimated, but following Ripley (Ripley 1981, p. 25) an approximate estimate is to treat the tows as if they were from a simple random survey and so take the sample variance (s^2_{simple}) of

$$\frac{C_i \; r_{v_i}}{D}$$

and to use this in the following equation:

$$V(I) = \sum_{i}^{tows} w_i^2 \, s^2_{simple}$$

This apparently only slightly underestimates the variance (Ripley 1981). It assumes that there is no periodicity in the oyster density with a wavelength that is the same as the spacings of the grid.

From Equation 1, and ignoring the variance of e because of time constraints, the variance for the total population, $V(N)$, is $e^2V(I)$.

2.3.3 Relative efficiency of vessels, r_v

This accounts for factors associated with the skippers and their vessels that affect catches (i.e., those unidentifiable factors that make one skipper or boat better than another). The overall efficiency of the sampling fleet is captured in the calibration constant, e, so the vessel effect (which implicitly includes the skipper effect as well) needs only to be a relative one. It was investigated by a 2-way analysis of variance, where each vessel, v, dredged at each of 10 common sites, i. The model used was

$$\log C_{i,v} = \mu + \mu_i + \delta_v + \varepsilon_{i,v}$$

where $C_{i,v}$ is the catch of legal-sized oysters,

μ is the grand mean,

μ_i is the site effect (i.e., effect of the oyster density),

δ_v is the vessel effect, and

ε is an error term assumed to be normally distributed with zero mean and a constant variance over all sites and vessels.

The log transformation was used to turn the multiplicative relative efficiencies into a linear model.

The vessel effects, δ_v, can be tested for statistical significance using a F test. If they were not significantly different at the 5% level, the relative efficiencies were set to 1; otherwise, they can be estimated by

$$\hat{r}_v = e^{\delta_v}$$

Because the δ_v's are constrained by $\Sigma_v \delta_v = 1$, the r_v's have a geometric mean of 1.

3. RESULTS

3.1 1990 survey

3.1.1 Distributions

High densities of legal-sized oysters occurred mainly in the eastern beds, with scattered patches south and north-east of the central beds which used to be the centre of the commercial fishery. Oysters were found over this central bed and out to the west in low densities (Fig. 2a), but old clocks occurred here in high densities (Fig. 3a). When the old clocks were converted into cumulative mortality (Fig. 4a) it is apparent that this area is where the past mortality rate has been highest. The deaths since the previous summer (1989/90, Fig. 5a), occurred in a ring towards the outside of the high cumulative mortalities area. This tends to be where the prevalence of *Bonamia* infection is also heaviest (Fig. 6a); the area with a moderate prevalence of infection formed a continuous ring around this and extended outwards slightly further, particularly to the east.

These distributions are consistent with the spread of *Bonamia* outwards from the central western beds where it was first found. The infection spread outwards as a wave of moderate prevalence of infection, followed by a wave of low mortality, followed by a wave of high prevalence of infection and high mortality. As the infection has spread the focus of the initial infection has remained as a core with a high density of old clocks and few living oysters. The highest densities of oysters in 1990 were found beyond the area infected by *Bonamia*.

3.1.2 Relative efficiencies of the vessels

The relative efficiencies of the vessels in 1990 were not significantly different (Table 1), therefore, unadjusted catches were used in the rest of the analysis.

Table 1: The relative efficiencies of vessels in the 1990 grid survey: two way analysis of variance on the log of numbers of legal-sized oysters per tow dredged by the five vessels at each of 10 sites.

Vessel code	Sites 1	2	3	4	5	6	7	8	9	10	Total
7320	5.11	5.68	5.73	4.50	5.81	5.31	4.22	4.88	5.73	6.54	53.51
9074	6.18	5.92	6.50	4.97	5.63	6.17	4.90	4.91	5.37	6.08	56.63
8263	6.82	5.20	7.33	5.09	5.70	6.52	4.62	4.67	5.68	5.06	56.69
8200	6.29	5.42	6.65	4.08	6.10	6.20	4.66	5.65	6.11	7.02	58.18
8203	6.15	4.89	6.02	4.34	5.15	6.38	4.72	4.64	5.84	7.23	55.36
Total	30.55	27.11	32.23	22.98	28.39	30.58	23.12	24.75	28.73	31.93	

Source of variation	Degrees of freedom	Sums of squares	Mean sums of squares	F
Sites	9	21.483	2.387	
Vessel	4	1.227	0.307	1.26[1]
Residual	36	8.768	0.244	
Total	49	31.478		

[1] Significance for $F_{4,36}$ at the 1%, 5% levels are 3.89 and 2.63

3.1.3 Calibration to the 1990 dive survey

The estimate of the absolute population size from the 1990 dive survey was 632 million. This figure had been adjusted by 4% to account for oysters outside the area covered by diving (Cranfield *et al.* 1991). The population of the dive area alone was 607.7 million. The population of oysters found in the dive survey area by the 1990 dredge survey (see Fig. 1a), I, was estimated to be 103.6 million. Dredge efficiency was calculated from the ratio of the two estimates, $e = 103.6/607.7 = 0.170$.

This e can be interpreted as the average dredge efficiency for the vessels and dredging protocol used, and also for the proportions of subareas of different substrate encountered (e.g. old shell, sandy gravel, sand) and the weather dredged in. As such, it cannot strictly be used for subareas, or areas outside the dive survey, or for the dive survey area if the proportions of different substrates change. It also needs vessels and skippers with the same efficiencies and the same dredging protocols. However, apart from the dredging protocol these changes are not under our control and so any effect of changes to e from these sources has been ignored.

3.2 1992 survey

3.2.1 *Distributions*

High densities of legal-sized oysters occurred only as scattered patches along two north-west diagonal corridors to the south and north of the original commercial beds(Fig. 2b). The areas of commercial densities were greatly reduced from 1990, and there were only two small patches to the south. The distribution of areas of high densities of old clocks had also shrunk (Fig. 3b) and the area with a density greater than 100 per tow had broken up into several patches. This suggests that ligament breakdown in clocks happened more quickly than new clocks were added at the present level of mortality. When expressed as cumulative mortality (Fig. 4b) the area within the 50% contour had remained about the same as 1990, but the 20% contour had expanded to the east and the south. The mortality rate since this summer (Fig. 5b) was far lower than for 1990. Areas of high mortality were at the extreme limit of oyster distribution. This may not be a fair comparison as the 1990 survey was done four months later in the year, which could have allowed a greater build up of new clocks.

The smaller area covered by new clocks and their lower density mirrored the distribution and lower prevalence of *Bonamia* in 1992 (Fig. 6b). The areas of heavy and moderate prevalence in 1992 were reduced and formed three patches. Parts of the area infected at the same heavy or moderate level in 1990 (Fig 6a) were lightly infected or had zero prevalence. In 1990, sites with zero prevalence occurred only to the extreme south and north-east of oyster distribution, but in 1992 these occurred widely through the central area of Foveaux Strait. The infection rate of *Bonamia* was still relatively high in the west, close to Stewart Island and in the northern area of Foveaux Strait.

3.2.2 Relative efficiencies of the vessels

The relative efficiencies of the vessels in 1992 were not significantly different (Table 2), therefore, unadjusted catches were used in the rest of the analysis.

Table 2: The relative efficiencies of vessels in 1992 grid survey: two way analysis of variance on the log of numbers of legal size oysters per tow dredged by 4 vessels at each of 10 sites.

Vessel	Sites										Total
code	1	2	3	4	5	6	7	8	9	10	
8263	4.43	3.18	5.28	5.44	4.92	5.00	5.05	5.27	4.33	5.61	48.51
8200	4.84	4.36	4.74	5.52	5.60	4.89	4.95	5.33	4.62	4.61	49.46
8203	4.74	3.18	4.85	5.26	5.20	4.26	5.32	5.93	4.08	5.92	48.74
8258	1.79	3.00	5.60	5.14	5.46	4.57	5.26	4.51	3.81	5.45	44.59
Total	15.8	13.72	20.47	21.36	21.18	18.72	20.58	21.04	16.84	21.59	

Source of variation	Degrees of freedom	Sums of squares	Mean sums of squares	F
Sites	9	17.153	1.906	
Vessel	3	1.45	0.483	1.36[1]
Residual	27	9.589	0.355	
Total	39	28.192		

[1]Significance for $F_{3,27}$ at the 1%, 5% levels are 4.6 and 2.96

3.2.3 Population size

The size of the population in the 1990 dive survey area, the 1990 grid survey area, and the total area covered in the 1992 grid survey were estimated from equation 1. The population of the 1990 dive survey area is an absolute estimate. This figure was used to calibrate the 1990 grid survey using the method explained earlier (*e*, dredge efficiency, was estimated to be 0.17). Dredge efficiency is affected by sea conditions and substrate type. On average the sea conditions for the dredge tows in both surveys were very similar (Table 3).

Table 3: Percentage distribution of sea conditions for dredge tows in 1990 and 1992 grid pattern dredge surveys

Beaufort scale	0	1	2	3	4	5	6	7	Mean
1990, 262 tows	1	2	9	55	24	8	1	1	3.3
1992, 379 tows	0	2	29	25	25	12	7	0	3.4

In 1992 tidal streams were stronger in the first 2 days of the survey than in 1990 (Table 4). Although this made control of the vessels more difficult, it is unlikely to have had any great effect on dredge efficiency. Allen & Cranfield (1979) found that higher ship towing speed resulted in higher dredge catches. Thus if tide had any effect on the 1992 survey it would most likely have resulted in an overestimate of the population in 1992 and an underestimate of the population decline between the two surveys.

Filamentous red algae often carpet the oyster ground in the eastern entrance of Foveaux Strait in summer. Fishers have found these algae filled dredges and greatly reduced their catching efficiency early in the season. Because the 1992 survey took place in the summer 4 months earlier in the year than the 1990 survey, the dredge results have been examined to see whether this could have influenced the comparison.

In the winter survey of 1990 filamentous red algae was caught at only 4 stations, 3 of them in the east around Ruapuke Island, 2% of the tows. In the summer survey of 1992 however, filamentous red algae was caught at 39 stations, 34 of them in the east around Ruapuke Island. This represents about 11% of the tows. Therefore, to the extent that red algae reduces dredge efficiency, the 1992 population estimate is likely to be an underestimate compared to the 1990 estimate. However, oysters were still caught in the 37 tows catching red algae, so the efficiency was not reduced to zero. given that the difference in numbers of tows with red algae between the two surveys was 9%, the difference in results is likely to be minor and within the experimental error.

A comparison of the percentage fullness of dredges shows some difference in fullness between years although the mean fullness did not differ greatly (Table 5). When these data were contoured (Figure 7a and 7b) with 25% and 40% fullness levels (the median and upper quartile levels), differences between 1990 and 1992 were apparent.

Table 4: Difference in height between high water and low water Bluff (proxy for strength of peak tidal stream) for each of survey 9–19 July 1990 (11 days) and 17 February–6 March 1992 (19 days). M = mean tidal height difference (m).

		Days 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
1990	Tidal height difference (m)	1.8	2.0	2.0	2.0	1.9	1.9	1.7	1.7	1.7	1.8	2.0									Total days fished 7
	stations fished	–	–	32	55	2	–	–	59	53	66	26									M = 1.84
1992	Tidal height difference (m)	2.4	2.6	2.7	2.7	2.6	2.3	2.1	1.8	1.5	1.2	1.3	1.3	1.5	1.5	1.7	1.8	1.8	1.9	2.0	Total days fished 7
	stations fished	–	51	–	–	90	–	95	–	–	–	–	–	56	–	–	32	–	17	63	M = 2.14

Table 5: Percentage frequency of fullness of dredges for all tows 1990 and 1992. M = mean percentage fullness.

	Percentage fullness 0	5	10	15	20	25	30	35	40	45	50	55	>55		
1990	10	5	14	4	11	14	12	0	10	0	13	1	8	N = 292	M = 27.3
1992	10	11	9	5	6	7	8	3	9	2	8	2	18	N = 374	M = 30.9

In 1990, tows in the central and eastern areas were largely more than 25% full. In 1992, few tows in the eastern areas were more than 25% full, but many more of those in the west and north were more than 25% full (Figure 7a, 7b). Furthermore, a greater number of tows in the west were more than 40% full. In spite of these differences, in no cases were the dredges fully saturated, so it is unlikely efficiency differed greatly between surveys from this cause. The numbers of single valves of oysters were not counted during either survey. However, available data indicate that in 1990 most of the hauls >40% full had large catches of clocks or live oysters (compare Figs. 3a and 7a) while in 1992 most of the hauls >40% full had either large catches of clocks (compare Figs 3b and 7b) or the catch records indicate they were full of single oyster valves. Therefore, the abundance of live oysters had little impact on dredge fullness in 1992.

The distribution of substrate in the common 1990 grid survey area was probably the same in 1992. Hence we have used the same figure (e = 0.170) to calibrate the 1992 estimate. The estimates of each of these populations and their 95% confidence intervals are set out in Table 6.

Table 6: Size of oyster populations (in millions of oysters) estimated in 1990 and 1992 with 95% confidence intervals. (e = 0.170)

	1990	**1992**	**% decline**
1990 dive survey area	607.7	241	60%
95% confidence intervals	497.7–717.7	189–293	
1990 grid survey area	689[1]	285[2]	59%
95% confidence levels	500–878	227–343	
Total population		319[3]	
95% confidence intervals		257–381	

4. ACKNOWLEDGEMENTS

Our thanks to the Oyster Boat Owner's Association who made these surveys possible. In 1990 Skeggs Ltd (Wilson Neil Fisheries) supplied four vessels and we are grateful for the managerial support of Brent Marshall and especially Margaret Evans who packed and ensured that all the 1990 *Bonamia* samples made it to the plane. We thank Lou Miller and his staff at Oyster Distributors for all their help and organisation of the mechanics of the 1992 survey and the packing and despatch of the *Bonamia* samples.

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[1] In Cranfield *et al.* (1991) this was estimated to be 632. The correction used for the population outside the dive survey area was 1.04. This underestimated the population outside the dive area which was 13% and not 4% of that inside the dive area.

[2] This population is slightly underestimted as the 1990 grid was not fully occupied during the 1992 grid survey. Some 10% of the outer area of the 1992 grid where stations were at 2 n.m spacing and oyster density was very low (mainly 0) in 1990, were not sampled in 1992 because bad weather reduced available sampling time.

[3] Estimate now includes the area west of Stewart Island and some area to the south of Foveaux Strait which were outside the 1990 grid survey area.

We thank all the skippers and oyster fishers, who's cooperation made both surveys successful. We thank the observers: Ben Judge, Adam Langley, Jake Keogh, Andy Greager, Julie Clifton, Kim George, and Steve Punnett.

We thank Sandy Black for her speedy and accurate punching of the data so that analysis was possible very shortly after the survey was completed. We especially thank Maria Fraser for her speedy word-processing of the rapid succession of drafts the report went through.

5. REFERENCES

Allen, R.L. 1979: A yield model for the Foveaux Strait oyster (*Ostrea lutaria*) fishery. *Rapports et Proces-verbaux des reunions. Conseil Permanent International pour l'Exploration de la Mer 175*: 70–79

Allen, R.L. and Cranfield, H.J. 1979: A dredge survey of the oyster population in Foveaux Strait. *Rapports et Proces-verbaux des reunions. Conseil Permanent International pour l'Exploration de la Mer 175*: 50–62

Becker, R.A., Chambers, J.M., and Wilks, A.R. 1989: The New S Language. A programming environment for data analysis and graphics. Wadworth and Brooks/Cole Computer Science Series.

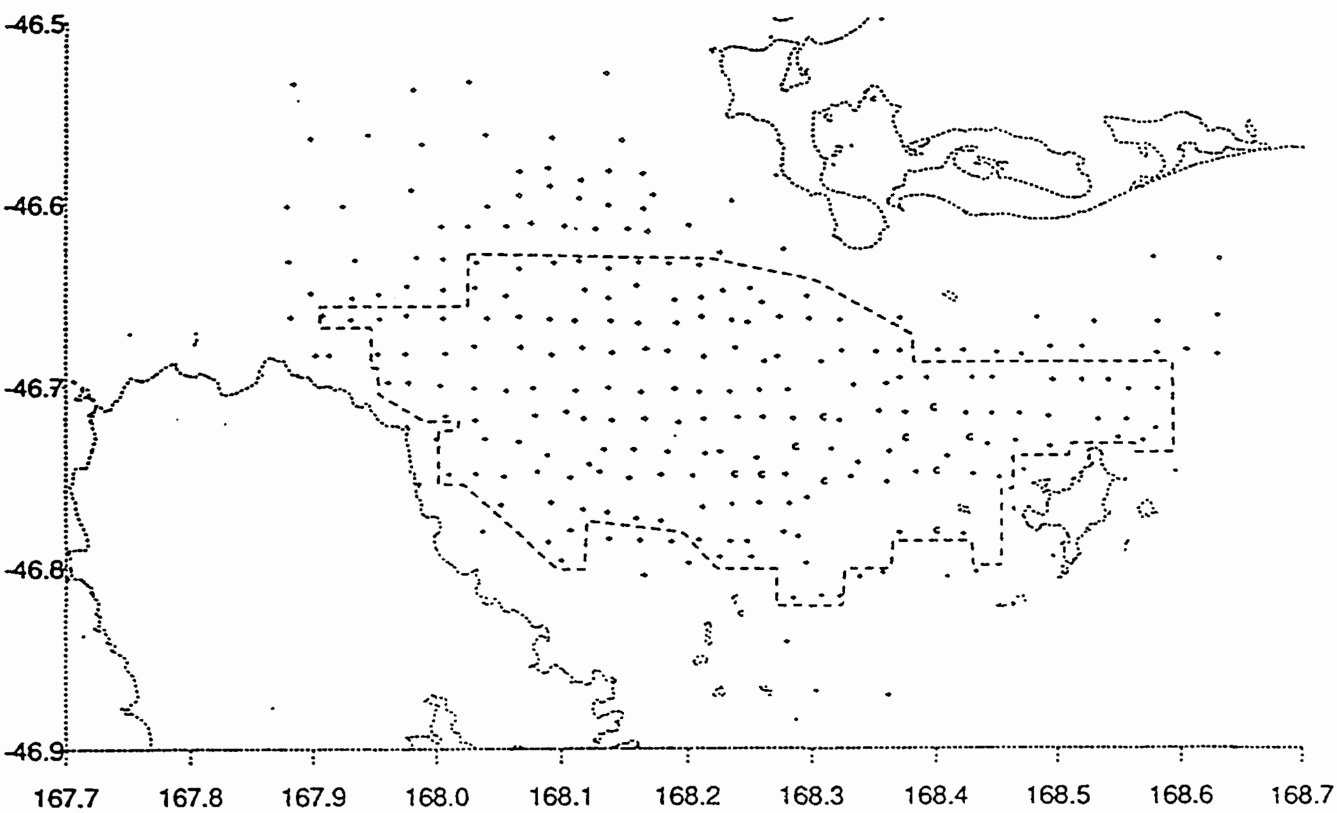
Cranfield H.J., Doonan I.J., and Michael, K.P. 1991: Assessment of the effects of mortality due to Bonamia on the oyster population of Foveaux Strait in 1990 and the outlook for management in 1991.*N.Z. Fisheries Assessment Research Document* 91/18, (Draft report held in MAF Fisheries Greta Point library, Wellington)

Dinamani, P., Hickman, R.W., Hine, P.M., Jones, J.B., and Cranfield, H.J. 1987a: Report on investigations into the disease outbreak in Foveaux Strait oysters, *Tiostrea lutaria*, 1986-87. MAFFish. N.Z. Ministry of Agriculture and Fisheries. 30 p. and 2 plates. (Preliminary discussion paper held in MAF Fisheries Greta Point library, Wellington)

Hine, P. M. 1991: Ultrastructural observations on the annual infection pattern of *Bonamia* sp. on flat oysters *Tiostrea chilensis. Diseases of Aquatic Organisms 11*: 163-171

Ripley, B. D. 1981. Spatial statistics. John Wiley & Sons New York. 252 p.

Figure 1a: Finish tow positions for the 1990 grid survey. Most are on an approximately 1 nautical mile grid, but some to the north-east, the north-west, and the south are on a 2 nautical mile grid. 'c' indicates the common stations dredged by all vessels. Overlaid is the 1990 dive survey area (dashed line). The grid samples within this were used to calibrate the grid survey with the dive survey.



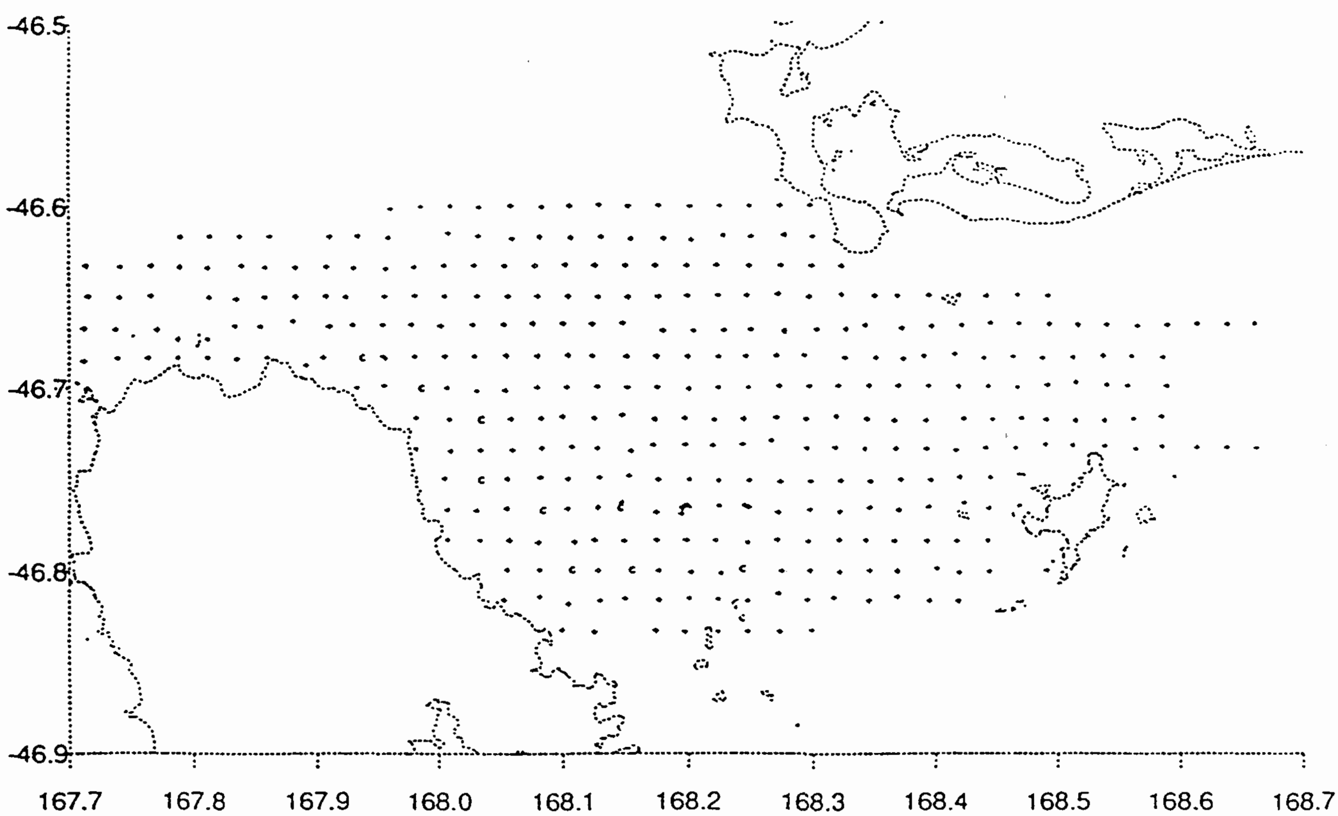


Figure 1b: Mid-tow positions for the 1992 grid survey. All are on an approximately 1 nautical mile grid. 'c' indicates the common stations dredged by all vessels.

Figure 2a

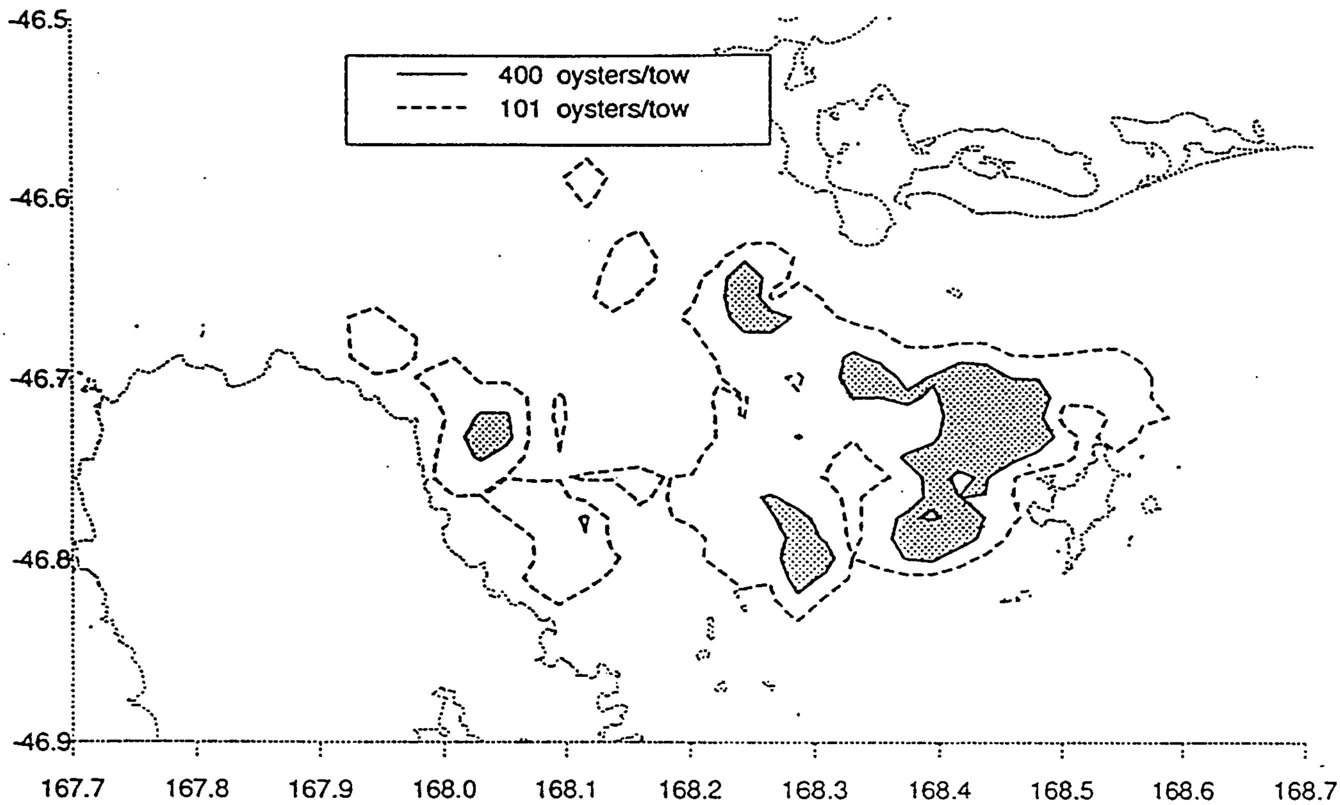


Figure 2b

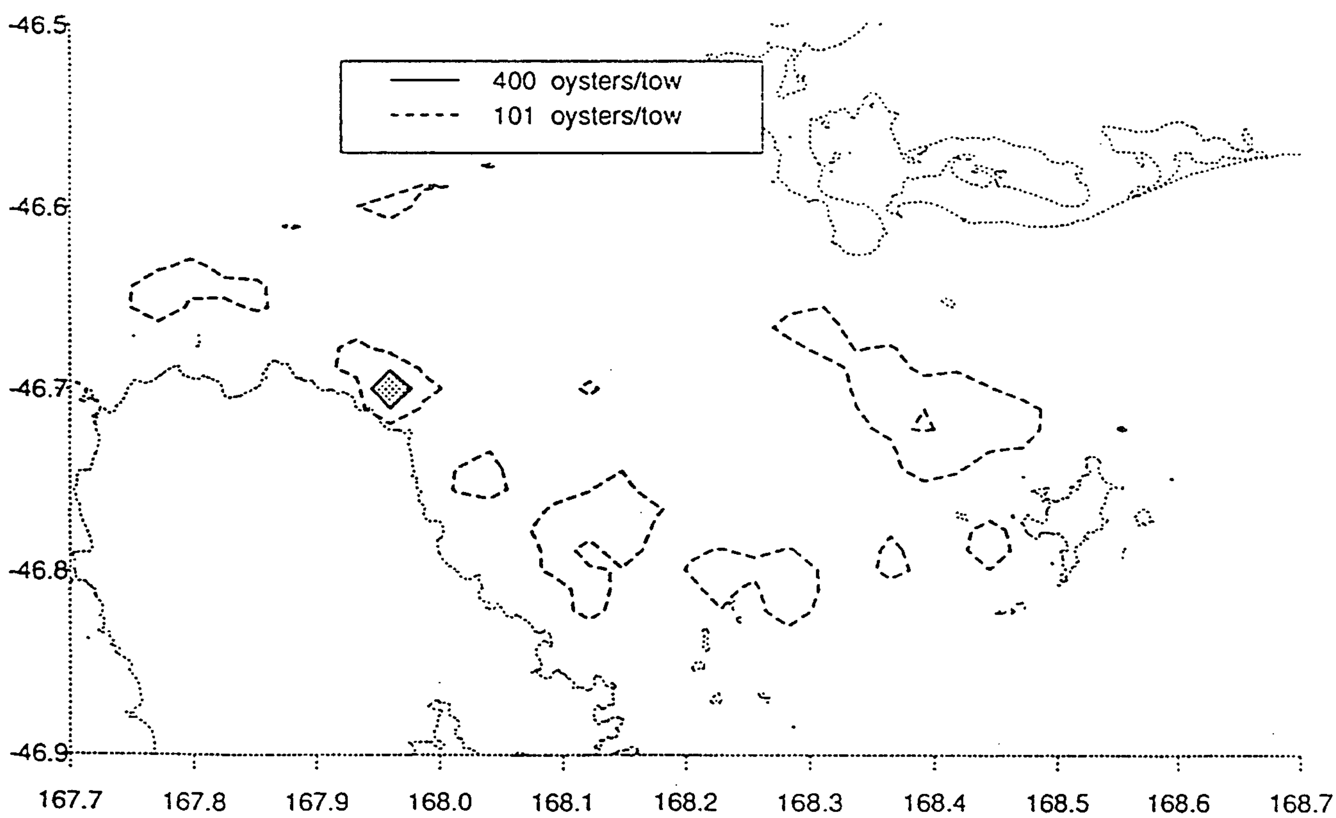


Figure 2: Legal-sized oysters (smallest dimension ≥ 58 mm) in Foveaux Strait: 101 per tow and 400 per tow contours. In 1990, 400 for the survey's standard tow was equivalent to the threshold for commercial density. 100 was median for tows that had oysters in 1990. (a) 1990, (b) 1992.

Figure 3: Old clocks (legal sized)in Foveaux Strait: contours are 100 per tow and 210 per tow which are the median and upper quartiles for the 1990 distribution of tows that caught clocks. (a) 1990. (b) 1992.

Figure 3a

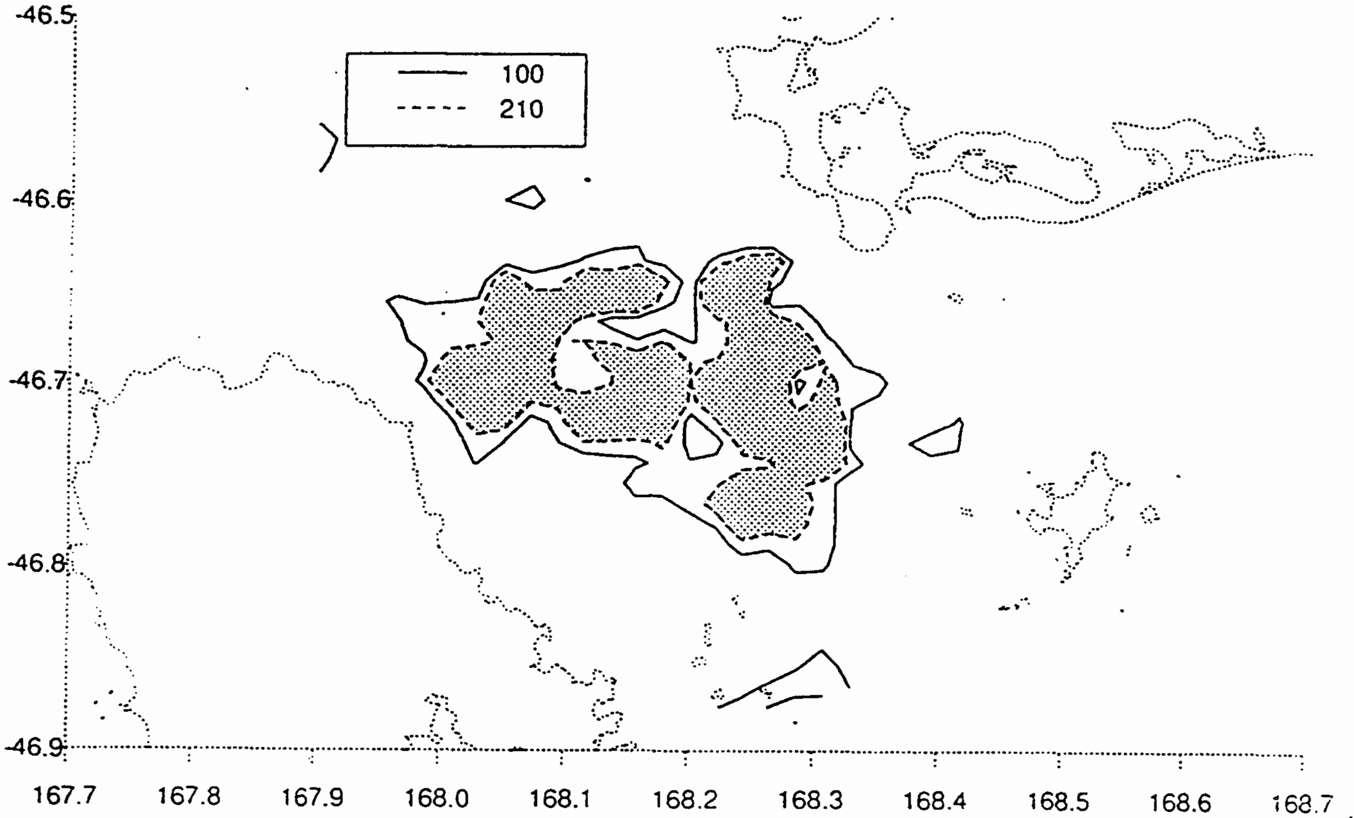


Figure 3b

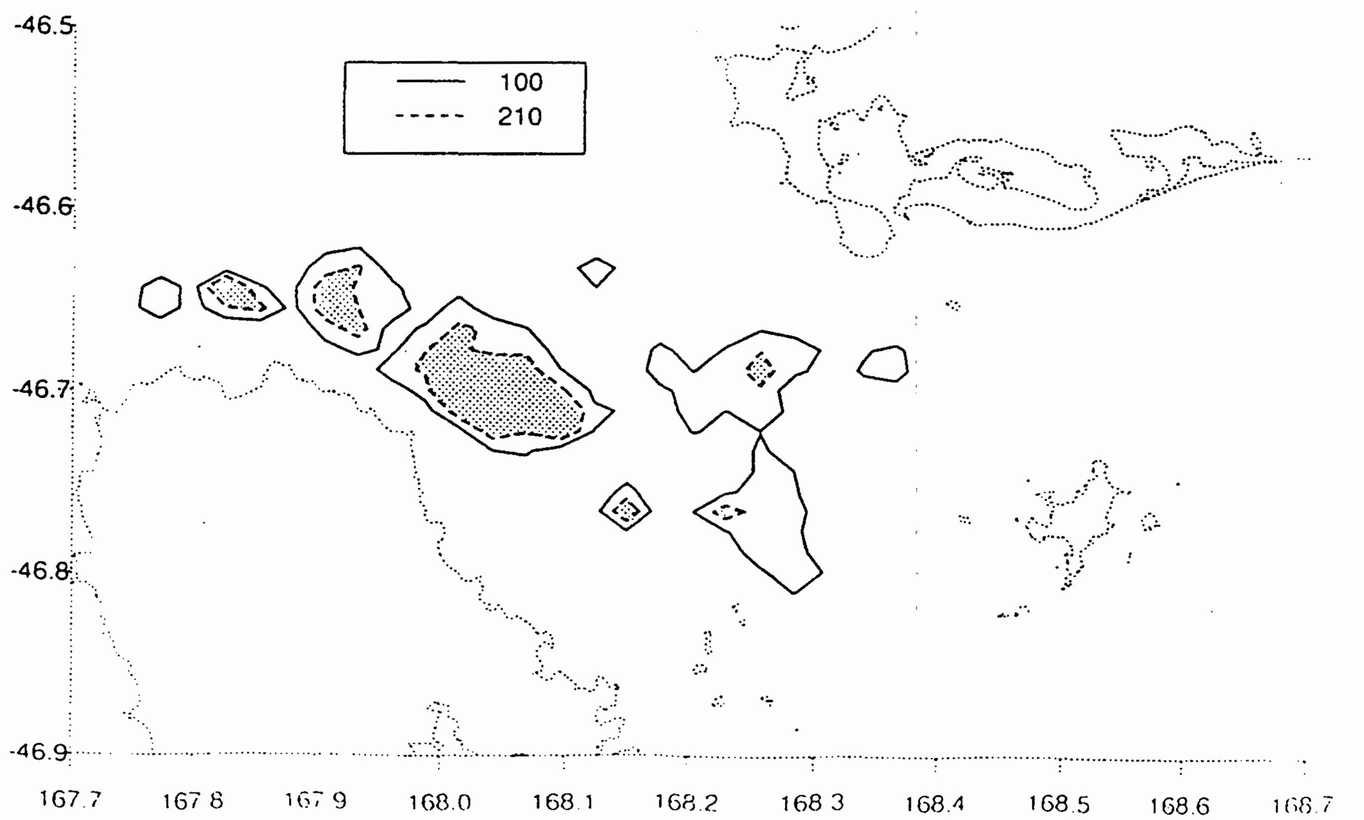


Figure 4a

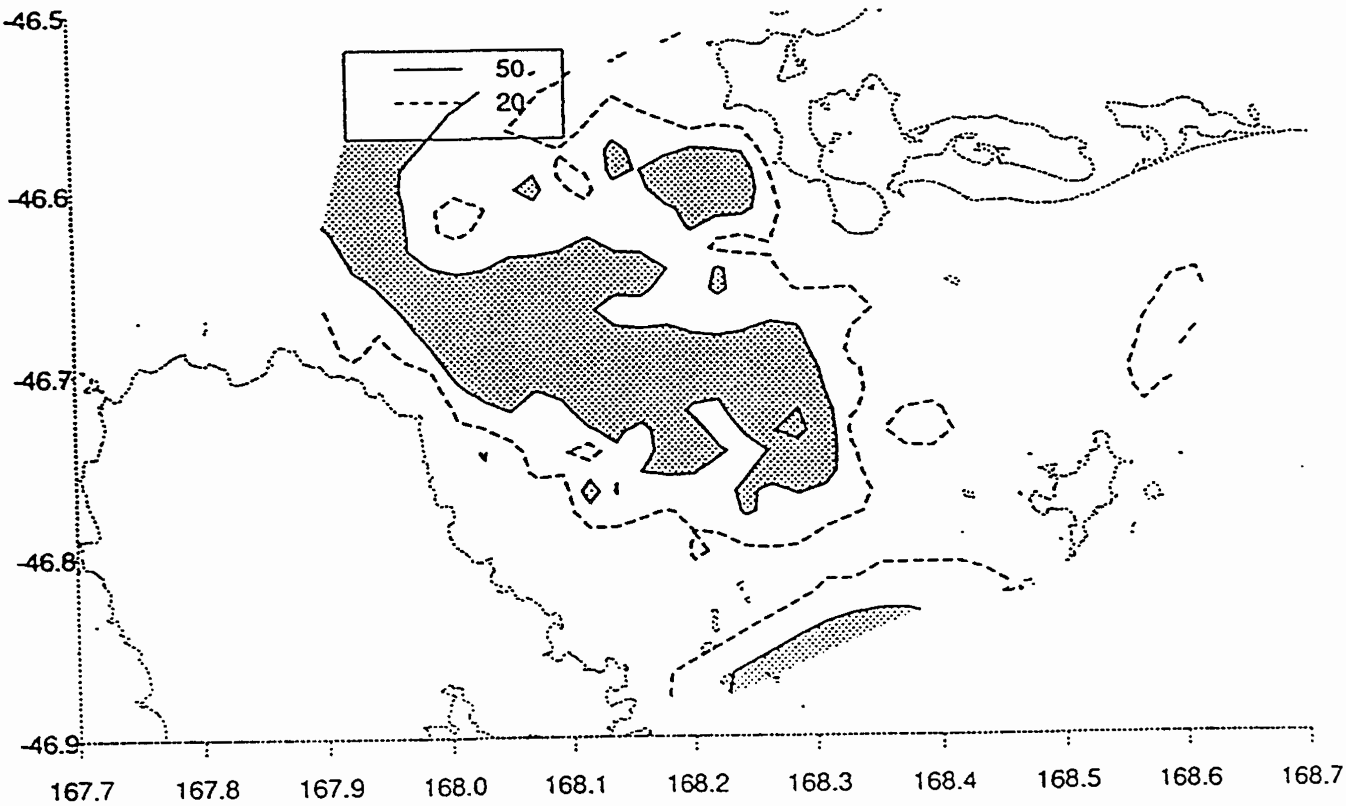


Figure 4b

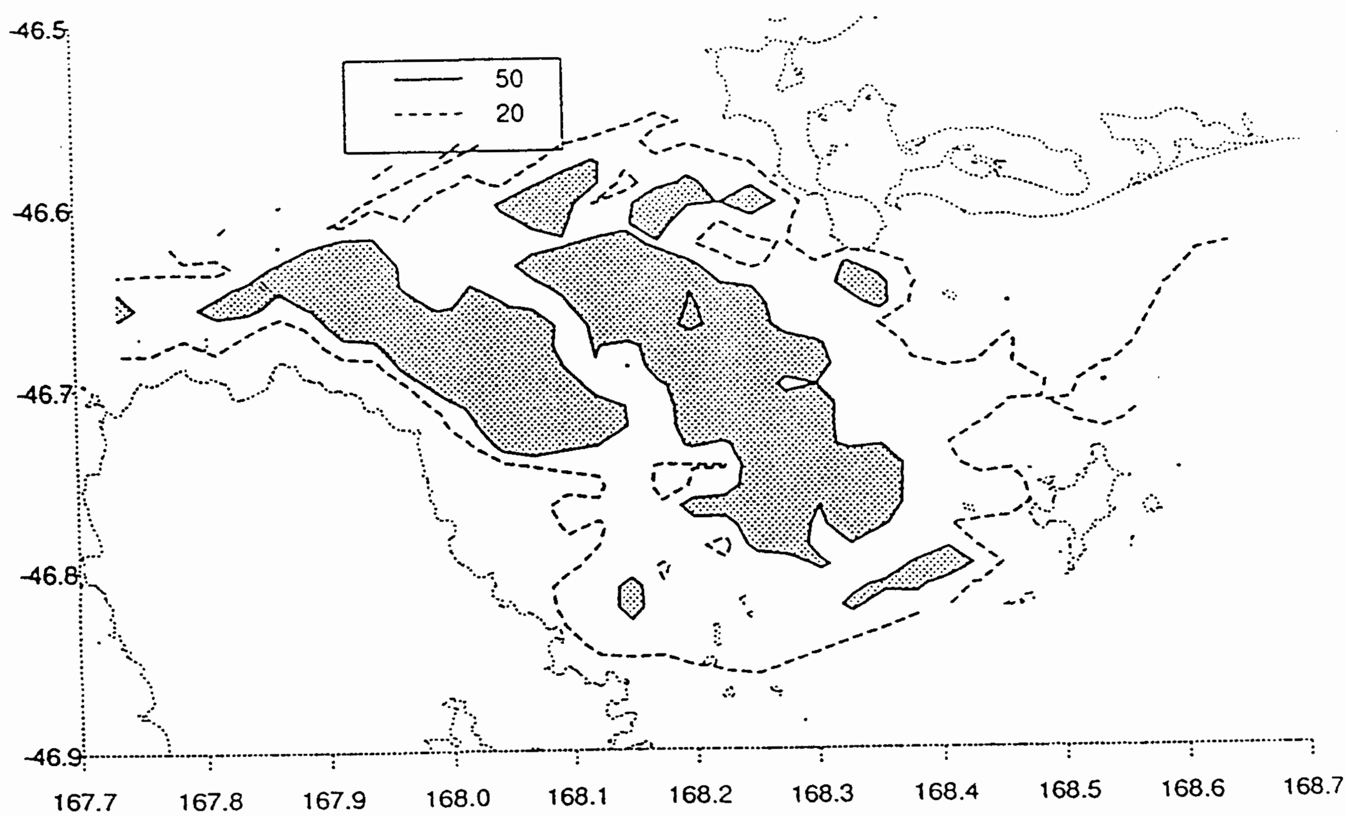


Figure 4: Cumulative mortality in Foveaux Strait: contours are 20% and 50% which are the lower levels of the cumulative mortality for sites sampled in 1986-87 that had a moderate and heavy prevalence of Bonamia infection. Cumulative mortality is calculated as the percentage of old clocks (legal sized) to the total numbers of old clocks, new clocks and oysters. (a) 1990. (b) 1992.

Figure 5: Recent mortality in Foveaux Strait: contours are 1% and 8% which are the median and upper quartile for the 1990 distribution in tows that caught new clocks and oysters. Mortality is calculated as the percentage of new clocks (legal sized) to the total numbers of new clocks and oysters. (a) 1990. (b) 1992; The largish area bounded by the 8% contour in the south of the plot is an artifact of the programs used to generate the contours and is based on one sample that had 1 new clock and 2 oysters, i.e., a mortality of 50%.

Figure 5a

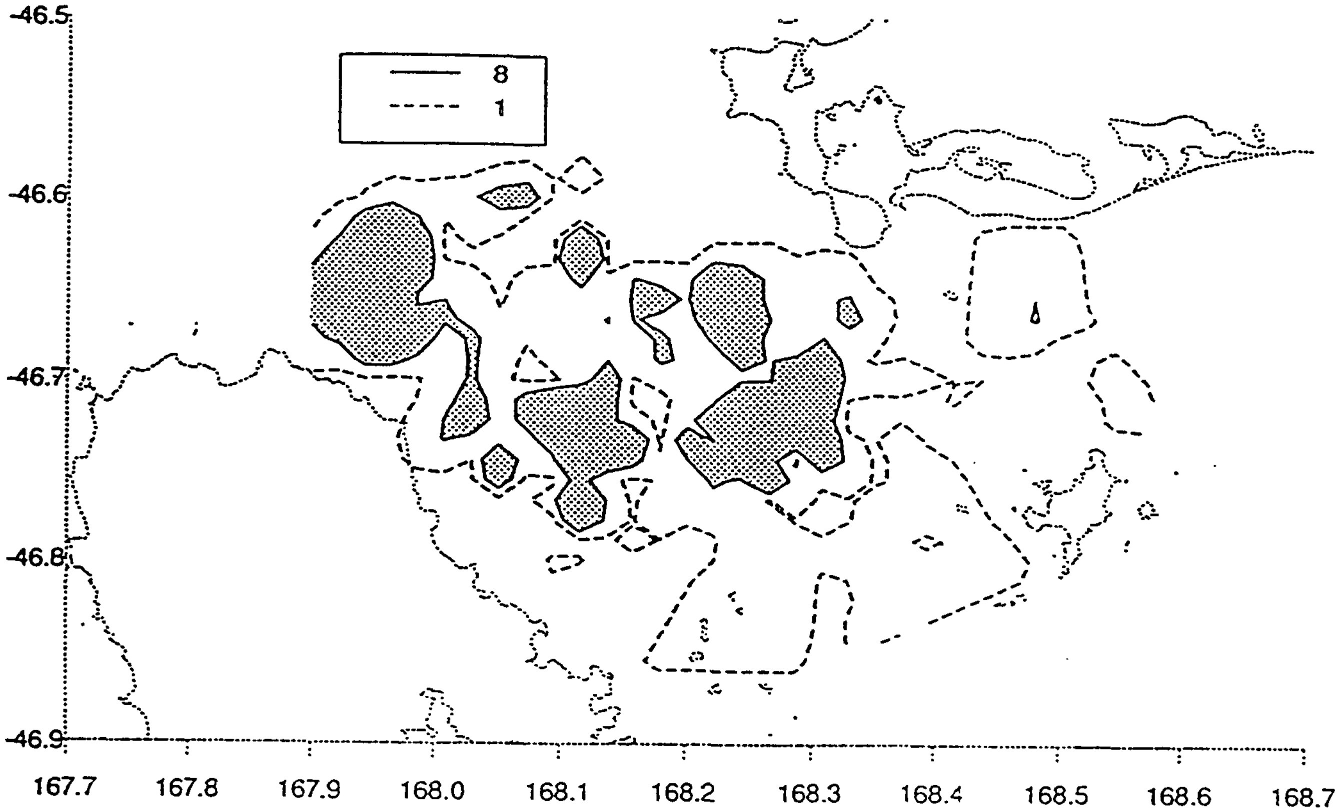


Figure 5b

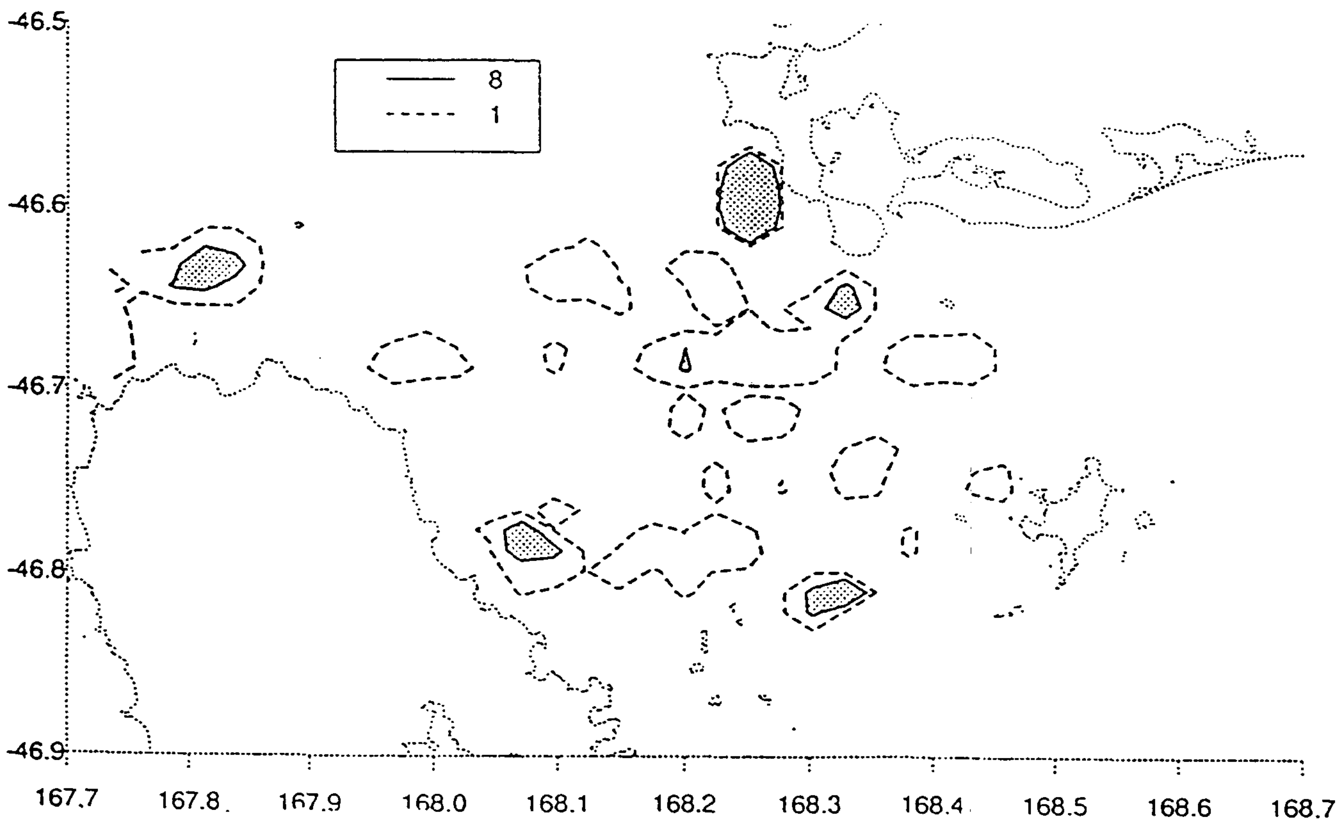


Figure 6: Prevalence of infection by *Bonamia*: contours are 10% and 25% which divides the range into light, moderate and heavy categories. O = *Bonamia* absent; l = prevalence was 1-10%; m = prevalence was 11-24%; h = prevalence >25%. (a) 1990. The western edge was truncated at a line joining Black Rock Point and Omaui Island because no sampling for *Bonamia* was done west of it; the infection probably lies further west than this line because all the western samples were heavily infected. (b) 1992.

Figure 6a

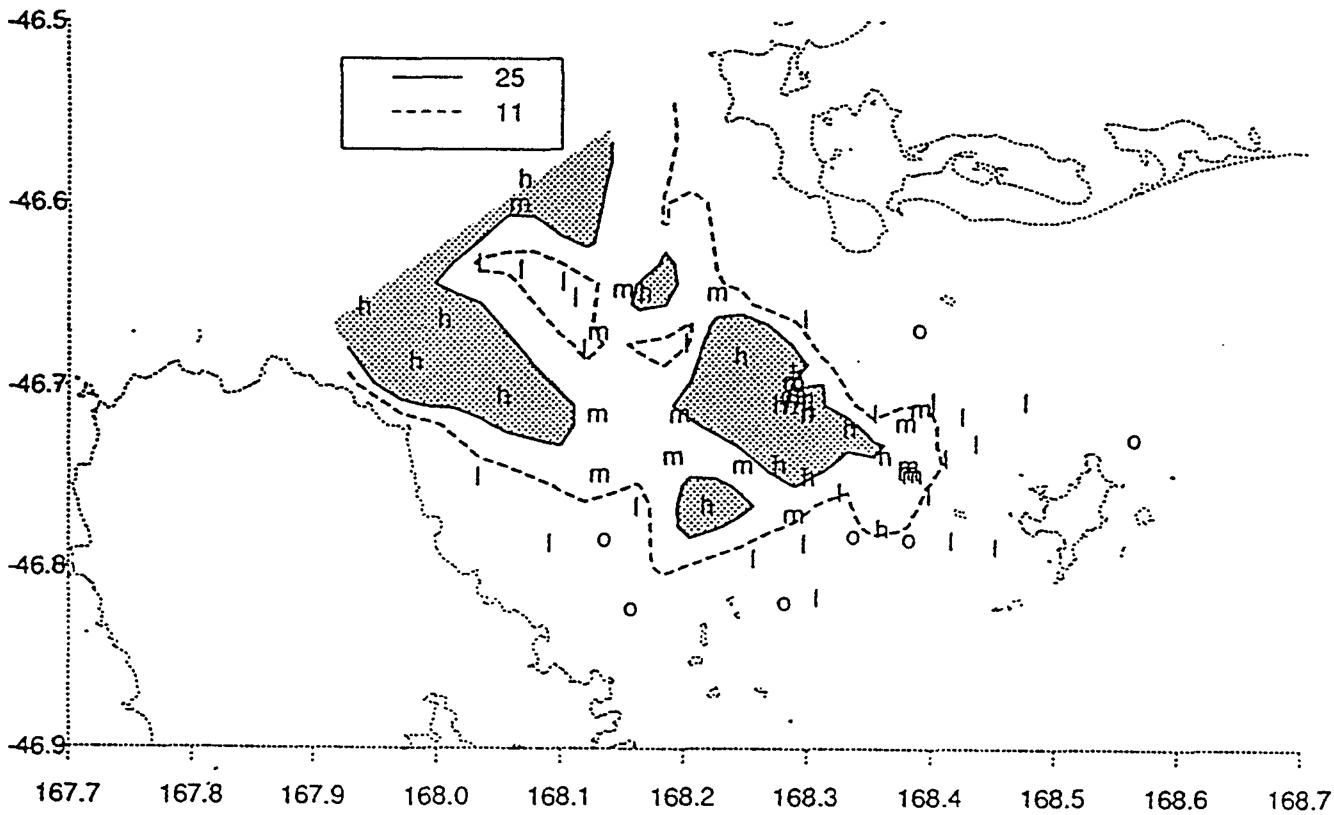


Figure 6b

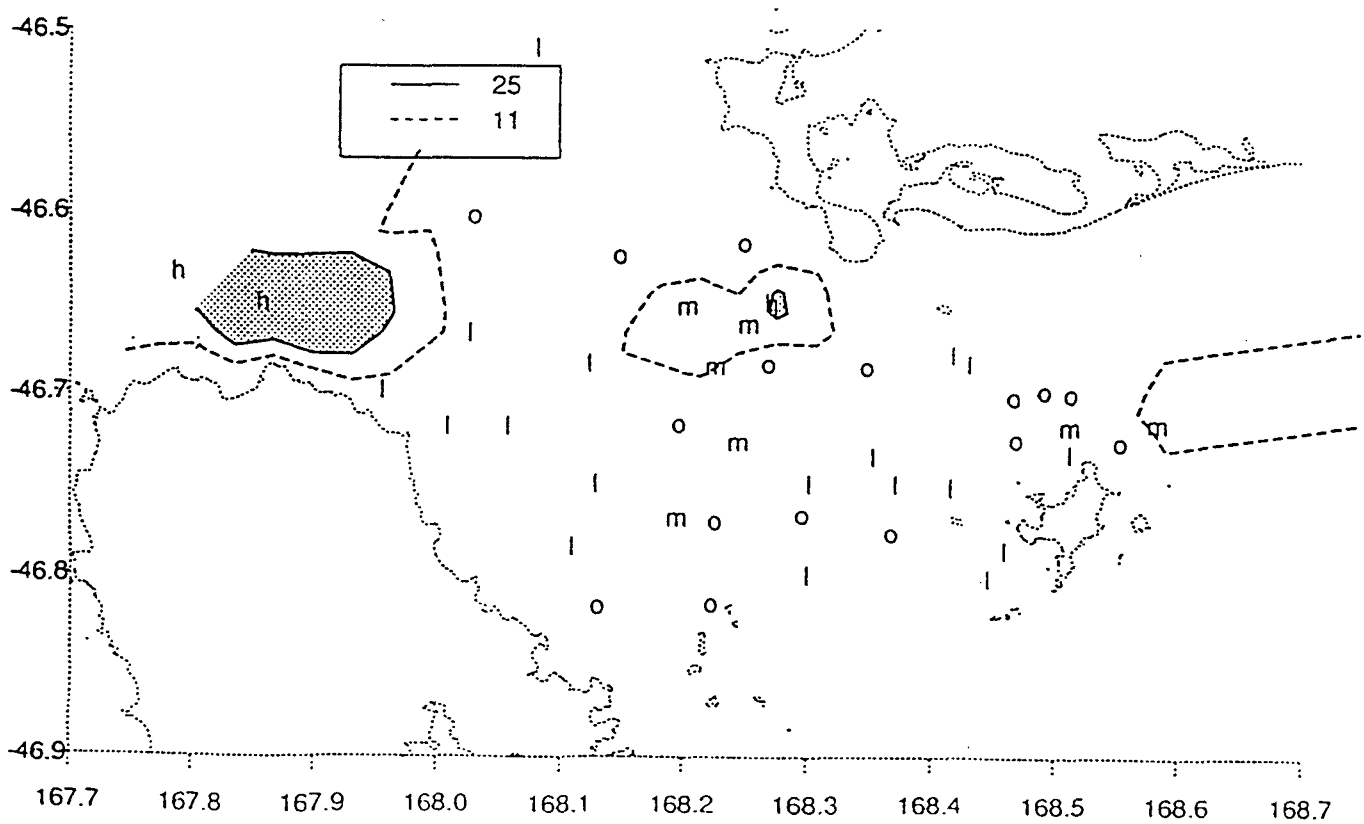


Figure 7: Percentage fullness of dredge tows: contours are 25% and 50% fullness. (a) 1990 (b) 1992.

Figure 7a

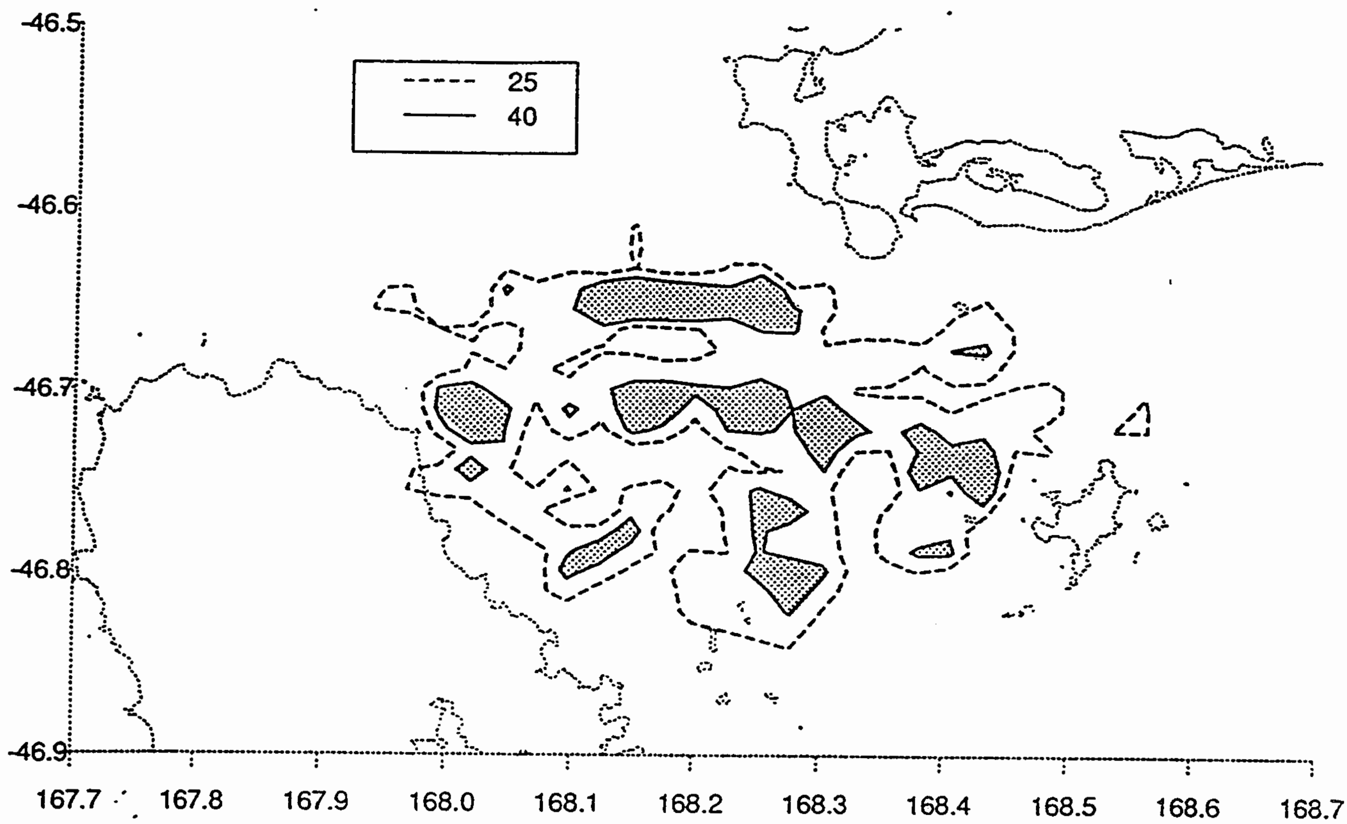


Figure 7b